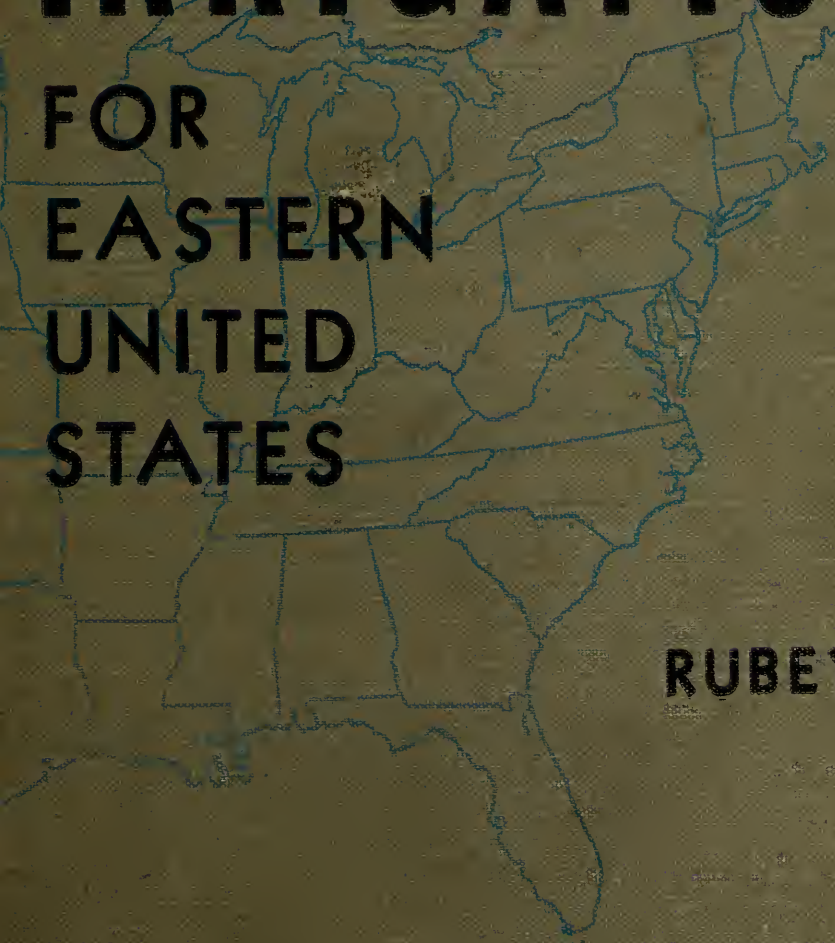
SUPPLEMENTAL IRRIGATION FOR EASTERN UNITED STATES



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SUPPLEMENTAL IRRIGATION FOR EASTERN UNITED STATES

by

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PREFACE

This book discusses where supplemental irrigation is advisable; how to plan, install, and operate a satisfactory system; and what to expect from it. The facts regarding supplemental irrigation are now well established, although not generally known, and will not change greatly.

Meteorologists give no hope of relief from damage due to irregular rainfall and the farmer must depend on his own efforts to raise his farming to a modern high level of production by installing his own supplemental irrigation.

The discussion is a practical one suitable for those who have little previous knowledge of the subject. The ten chapters of the text will suffice for general reading; the Appendixes will furnish technical and practical details; and the References of Appendix G will give the best written material available.

The author has designed, constructed, and managed large and small irrigation projects in the West and has attempted to adapt those practices to the smaller developments of the East, of course keeping in touch with eastern progress. The methods described have proved their worth. Sprinkling predominates in the East and surface methods in the West. Modifications of these practices will develop under special conditions but they should be adopted only when fully accepted; otherwise, they are apt to become pitfalls for the unwary.

While the book gives the generally needed information, it is still advisable to consult irrigation and other experts before investing, at least during early years of operation.

No attempt is made to discuss the details of culture for any particular crop in any particular region since these are constantly undergoing change and improvement. Teachers of agriculture and other advisers must keep the farmer posted on late developments.

Following World War II it became apparent that the interest in, and installations of, supplemental irrigation gave promise of a new industry growing along with farm equipment, electronics, television, and air conditioning. This growth is being realized in all these mechanical fields.

Assuming that a rapid expansion of supplemental irrigation was coming, the author prepared a Bulletin of the Engineering Experiment Station of the University of Missouri entitled

Supplemental Irrigation for Missouri and Regions of Similar Rainfall and it appeared in 1945. About that time manufacturers expanded their output of light-weight pipe and sprinkler systems, and dealers stepped up the promotion of sprinkling. In order to keep abreast of these developments, the Bulletin was revised three times, finally in 1953. By this time a more comprehensive treatment was necessary, hence the present book which is the first relatively complete treatment of this subject.

The material presented has been gathered through a generation of time from many sources, persons, and experiences. The United States Bureau of Reclamation is quoted extensively as the outstanding authority for irrigation, even though it operates only in the West. So far as possible credit is given throughout the book but appreciation is also expressed gratefully here. Progress in irrigation, as in most things, results from the combined efforts of many people.

January, 1954. The Author

Editor's Foreword

The use of supplemental irrigation in vast sections of the country which have never been irrigated would add a new dimension to farming. It seems almost certain that the practice will spread and it may spread rapidly. Alert farmers and the teachers and advisers of farmers should be prepared for it.

Professor Rubey, the author of this book, has the backgrounds of practical experience and theoretical training necessary to indicate the possibilities and limitations of supplemental irrigation and the precautions to be observed in its use. He has adapted to the more humid sections the practices developed through generations in the arid parts of the West. Certainly the East has much to learn from the West about the use of water in increasing farm production and making it more certain.

The techniques of supplemental irrigation are here and have been used successfully in many of the sections to which it is adapted. But their introduction is not as simple as exchanging open-pollinated for hybrid corn; their use involves almost a new way of life for the farmers who use them. It took 15 years completely to introduce hybrid corn in two Iowa townships; unless our procedures in introducing supplemental irrigation are much better, we can predict that farmers will wait a much longer time before realizing its advantages.

Technical advisers and demonstrations of practical use are all-important in getting the new irrigation practices established. An educational program through the schools, agricultural extension, and other agencies is as urgently needed. Farmers will have to get used to a big and complex new idea, change some pretty fundamental attitudes, and replan much of their farming if large-scale benefits are to be derived from supplemental irrigation. Helping farmers to see the advantages to be gained and the sacrifices that must be made to gain them, so that they may decide intelligently what to do and act accordingly, is the task of our agencies for agricultural education, an enormous task in this particular instance.

It is believed that the book will be useful to all concerned: to farmers, to technical advisers, and to those who teach farmers. Since it is now the only book on the subject, it may be almost indispensable in effecting a major revolution in American farming.

H. M. HAMLIN
Editor

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Chief Agronomist, National Fertilizer Association

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CHAPTER I

INTRODUCTION

Since World War II the management of industry has become professional; invested capital and operating costs have risen; and the whole production and distribution process has changed decidedly to become more orderly, more certain, and more profitable.

Similar advances have been made in agriculture. The best farm practices developed by research and experiment are being passed on to farmers by teachers of agriculture and by other agricultural experts located in the counties, in the colleges of agriculture, and elsewhere. Equally important, federal support or other methods of stabilizing crop prices at reasonable levels seems assured and the age-old hazard of ruinous prices may be a thing of the past.

Summary

The final step of guaranteeing adequate moisture for the best plant growth remains to be taken. Then farmers, like industrialists, will be in position to perfect the farm and its operating conditions, and on this modern basis to run the farm on a factory-like planning and scheduling with greater certainty of output and profits. This is being done at Seabrook Farms, referred to later. Without irrigation, a farmer may become a marginal crop producer.

The remaining critical hazard in the eastern half of the United States is the uncertain and poorly distributed rainfall, and this is now the only factor preventing planned, scheduled, and heavy crops in that region. Since rainfall supplies most of the moisture needed here, the water added artificially is called *supplemental irrigation* as contrasted with the much heavier and more expensive irrigation in the western states where little or no rainfall occurs during the growing season, but where very large crop yields are planned and harvested year after year with a regularity unknown in the East.

Supplemental irrigation is the only way to prevent the savings and plans of years from being wiped out by serious

droughts. The major droughts of 1934 and 1936 in the Corn Belt and the Great Plains, the drought of 1952 in the South and New England with some fourteen states declared disaster areas, and the general drought of 1953 proved that most localities in the humid East are subject to drought as a disaster. Often drought years are close together and the disastrous results are accumulated.

The less noticeable dry spells are even more serious, especially the lack of rainfall which occurs most years at critical periods of growth. These irregularities in rainfall reduce crop yields, eat away profits year after year, prevent the intensive fertilization and close spacing of plants that are essential for maximum yields and profits in all years, and prevent that permanent and regular year-after-year farm and livestock program which is essential to a well-managed agricultural operation.

But the famous dictum erroneously attributed to Mark Twain, "Everybody talks about the weather but nobody does anything about it," is no longer true.

Much progress in supplemental irrigation has been made in recent years, and it has become recognized that its adoption for maximum profit requires a higher type of culture than did non-irrigated farming. This improved culture returns large profits in crop yields, often over 100 per cent on the annual cost of irrigation. It also gives assurance that the permanent farm and livestock program will continue without interruption from dry weather of long or short duration.

Irrigation is not suitable everywhere and therefore many farms can never attain maximum production. It must be carefully planned and it will not be successful if undertaken in a half-hearted manner.

Supplemental irrigation should be used in most years on most crops, not only in obvious droughts, and preparation must be made long before the crops are planted. When dry weather comes it is too late.

The extension of supplemental irrigation throughout the East will ensure uniform maximum crops because rainfall is inadequate in amount or distribution through most seasons, will ensure increased quality and quantity of crop yields, will permit a larger plant population and a more profitable use of fertilizers, will permit better crop and equipment scheduling, and will permit

raising high-value seed and other crops which are not being grown intensively locally at the present time. Preparing the land for surface irrigation often aids drainage and facilitates farm operations and early spring plowing.

Irrigation will greatly increase land values as it has in older irrigated districts. The diversification of agriculture resulting from irrigation will be helpful. Those who secure large and choice crops by irrigation and use of fertilizer will usually benefit also from higher prices. Doubling of yields, or 100 per cent return on the annual irrigation cost, is not uncommon. When irrigation practices improve, even greater benefits will be realized.

As farm income continues at a relatively satisfactory level, profitable and permanent improvements on the land such as supplemental irrigation provide an excellent investment for surplus funds.

The East should capitalize on the competitive advantage it possesses over arid regions* because irrigation there is less difficult and less expensive, because no costly pioneering settlement is needed, and because better and closer markets are available. The irrigable acreage in the East will be larger than that of the western states.

Although supplemental irrigation in humid and sub-humid regions has been practiced in a limited manner since ancient times, it is only in recent years that it has been extended over two and one-half million acres east of the 100° meridian of this country and developed on a systematic, economic, and scientific basis. The 100° meridian passes through the centers of the Dakotas, Nebraska, and Texas and through the western ends of Kansas and Oklahoma. Recent expansion of supplemental irrigation has been rapid and many improvements are available. However, the movement is in its infancy, greater returns are yet to come, and its literature is scattered.

It is the purpose of this book to summarize the possibilities of supplemental irrigation for the East, to advocate successful practices for eastern conditions, to warn against pitfalls, and to provide a selected list of annotated references.

A High Type of Crop Culture

The supplemental irrigation here advocated is not simply adding a little water to ordinary farming operations, but rather

*The 1941 Yearbook of Agriculture, pp. 195-6.

is the foundation for a new, improved crop culture which differs considerably from the usual farming without irrigation and which returns large profits. It is not recommended that supplemental irrigation be undertaken unless on a thorough and permanent basis accompanied by a high type of culture which will include the following items.

1. Intensive Fertilization: Without irrigation, fertilizer applications can be increased profitably only as much as is justified by the probable amount and distribution of rainfall. In recent years, and particularly in dry 1952 and 1953, this profitable limit often has been exceeded when rainfall was insufficient, and an unfavorable impression has been created of the value of heavy applications of fertilizer. Too much fertilizer with too little water may be harmful. As a matter of fact it is impossible to estimate and balance carefully the amount of fertilizer used with the always uncertain amount and distribution of rainfall for the coming season.

On the contrary, if supplemental irrigation is available, the total applications of rainfall and irrigation will be furnished at the right time and in the right amount. With moisture thus controlled the maximum profitable fertilizer application (chemical, barnyard, or green) needed for a proposed maximum yield may be estimated accurately by experienced advisers and used safely with no danger of over-fertilization.

2. Closer Spacing of Plants: Based on the proposed maximum yield as chosen in item (1) above, the number of plants per acre needed to produce the yield can be accurately estimated and planted according to good standards of practice and cultivation. It is then almost certain that the anticipated maximum yield will be attained since both the plant nourishment and water required will have been furnished.

3. Selected Strains of Plants: As in any high standard of culture, the strains of plants must be found experimentally that will produce the most satisfactory yield under the irrigated conditions in (1) and (2) above. They may not be the strains used in non-irrigated farming.

4. Scheduling of Crops: Thornthwaite (Reference 34 and others) has developed a basis for scheduling the planting and harvesting of irrigated (not dry-farmed) crops which will aid in

(a) Planting at the most favorable time,

(b) Maturing at the best time for marketing and other advantages,
(c) Raising more than one crop per season on the same land and plowing and planting early,
(d) Balancing farming as mentioned in (5) following, and
(e) Minimizing the investment in farm equipment by scheduling it for use on a maximum number of days.

Based on adequate moisture being always available from irrigation, Thornthwaite has constructed a graphical scale, soon to be available, which gives the crop scheduling basis for any part of the United States. For a particular crop, it shows when that crop will mature after planting on a chosen date, for any given latitude. However, it must be remembered that it applies only when adequate moisture is available to the crop and of course this means under supplemental irrigation.

5. Balanced farming. Also weed and pest control.

6. Essential Education and Advice: It is even more important that irrigated farming be practiced under the best education and advice available than is the case with the older non-irrigated farming. Not only is there more capital invested and more operating expense and labor involved, but a newer and better planned farm program is needed which does not follow older and better known practices.

Educationally, teachers of agriculture will have a large part in developing the understandings, appreciations, and changes of attitude necessary, and in time they may be expected to be teaching unit courses on the subject with related, on-farm practice. County agents, advisers from colleges of agriculture, and Soil Conservation Service men in many regions, all can contribute to successful irrigated farming and must be consulted.

Recently a secretary of agriculture truly said, "The basic long-range needs of American Agriculture are to reduce costs, to improve quality, and to expand markets. The sound approach to every one of these needs is through research and education."

Examples and explanations of the several foregoing items are given throughout this book.

Experience Available

Seventy-one thousand acres were under successful supple-

mental irrigation in the Willamette Valley of Oregon, according to the 1950 U. S. Census, and plans are now underway to increase the acreage greatly. Of the total annual rainfall of 38 inches only 6 inches falls in the five summer months. Considerable data are available from this region where supplemental irrigation has been practiced over 40 years, and where the author was engineer and manager of an early project. See especially References* 6, 12, 52, 59, 203, 213, and 219.

More recently the Tennessee Valley Authority, the University System of Georgia, and agencies of adjoining states have conducted experiments which show supplemental irrigation to be profitable even in that region, where the annual rainfall is more than 50 inches. See References 8, 13, 16, 17, 33, 38, 39, 57, 62, 65, 69, and 70.

One hundred and twenty-five thousand acres of corn have been irrigated successfully in Eastern Nebraska.

In the devastating southwest drought of 1953, one progressive rancher raised 1500 bales of cotton, 1 per cent of the total crop of the Rio Grande Valley, by supplemental irrigation from 10 deep wells.

A study many years ago (Reference 4) found 108 places in Missouri where irrigation was practiced on a small scale with fairly satisfactory results, although often the techniques were crude. Many of the facilities were emergency installations necessitated by the serious droughts of 1934 and 1936, and they were neither planned nor operated to secure the best returns.

Seabrook Farms near Bridgeton, New Jersey, in 1951 sold $23 million worth of frozen fruits and vegetables raised partly on its own 4,000 acres of scientifically irrigated land. Nothing is left to chance from the original crop scheduling onward through planting, irrigating, freezing, and marketing but all is carefully planned in detail as far as two years in advance. A staff of chemists, home economists, bacteriologists, climatologists, and irrigation engineers is always on duty. Such planning accounts for the growth from a 60-acre farm to the largest integrated truck farm and quick-freezing plant in the world. See References 32, 34, 36, 37, and 41.

Satisfactory results, examples of which will be found in References 2, 7, 11, 24, 31, 40, 63, 64, 66, 67, 68, 71, 72, 74, 75, and 102, have been obtained in other humid and sub-humid

*These and subsequent references are listed in Appendix G at the end of the book.

regions. Over one and one-half million acres of rice and citrus land are irrigated in the wet South.

In few of these cases has the irrigation been accomplished under the best conditions that are modernly possible, and much better results will be obtained as advantage is taken of the latest experience, advice, and improvements.

In a 1952 estimate based on the 1950 U. S. Census plus normal increase and recent reports from agricultural colleges, Colonel C. R. Pettis estimates that the humid East had 32,000 farms totaling 2,600,000 acres under supplemental irrigation, as compared with 304,000 farms totaling 26,000,000 acres under full irrigation in the arid West.

Colonel Pettis makes an interesting prediction of reasonable prospective yields for irrigated crops as follows. Though these estimates appear optimistic, they are practical goals at which to aim.

Alfalfa	7	tons
Apples	400	boxes
Beans pole	350	bushels
Beef	500	pounds
Cabbage	12	tons
Cauliflower	8	tons
Corn	150	bushels
Cucumbers	12	tons
Grapes	5	tons
Lespedeza	5	tons
Lettuce	9	tons
Milk	7500	pounds
Onions	10	tons
Oranges	350	boxes
Peaches	350	crates
Potatoes	350	bushels
Sweet corn	1500	dozens
Sweet potatoes	400	bushels
Tomatoes	10	tons
Turnips	12	tons
Turnip greens	10	tons

Thornthwaite in Reference 37 states:

> As I have said, the progressive farmer in New Jersey produces 400 bushels of potatoes per acre. But with supplementary irrigation the yield rises to 600 bushels and when water is scientifically scheduled, 800 bushels per acre are obtained. Since this latter figure is still far below the record yield of 1300 bushels per acre, we can foresee the time when the good farmer who is using irrigation properly will produce 1000 bushels of potatoes to the acre.

> Our good farmers produce 80 bushels of corn to the acre. But the record corn yield in the United States is above 250 bushels per acre.
>
> These examples show that we still have a long way to go before we reach the limits of productive capacity of our crop plants. They also confirm what we have learned from vegetable production, that scientific irrigation greatly increases the benefits of all other good farming practices; fertilizers, improved seed, and pest control. Irrigation is necessary to high yields, and a perfected technique of irrigation is required for maximum yields . . . . .
>
> The practice of irrigation is not yet scientific, however, because farmers do not know how much water is needed nor when water should be applied. Often, water has been applied late or in insufficient amounts. On the other hand, it has sometimes been used in excess. The use of supplementary water has not increased crop yields as it should.

Examples of Irrigated Crop Planning

With sufficient water for growing corn assured by supplemental irrigation, the reasonable yield to be expected from a suitable field should be estimated (well over 100 bushels per acre), the strain best suited to irrigation selected, the plant population determined with a Plants-Bushel Ratio (PBR) of 100 or less, and fertilizer and barnyard or green manure applied under competent advice in proportion to the expected yield. This type of procedure on 125,000 acres of corn under supplemental irrigation in eastern Nebraska is producing large yields. It illustrates the planning of a high type of culture under supplemental irrigation which is suitable to many crops.

As another example, mention should be made of irrigated pastures (References 60, 61, 63, 64, 68, 69, 70, and 73) which have proved so helpful on livestock farms and which illustrate a kind of self-harvested crop that reduces the labor required. With non-irrigated pasture almost burned up throughout the South and East in 1952 and the Southwest in 1953, irrigated pasture was often supporting three mature beef or dairy animals per acre as against one animal on dry pasture. Fall pasture seeding is often facilitated by irrigating after the seeding.

From Reference 63 and from *Agricultural Engineering*, Vol. 32, No. 3, pp. 163-165, March, 1951 are quoted the detailed conclusions for carefully conducted irrigation of pasture in Southern Illinois during 1949 and 1950. Average annual rainfall is 45 inches. Even more encouraging results were secured later but are not available in published form.

The following results were noted during two years of irrigation:

Where equipment is available for determining available soil moisture, irrigation should be started when the soil moisture is 65 per cent utilized, perhaps 50 per cent for maximum production.

When rainfall is less than two inches in two weeks during the summer, additional moisture must be applied to maintain maximum growth under southern Illinois conditions. Two-inch applications were more economical than one-inch applications.

Both forage yields and animal gains have been significantly increased by irrigation, 100 per cent with poor rainfall and 53 per cent with good rainfall.

The use of supplementary water seems to make the limestone available more rapidly with a more rapid increase in the pH level.

Higher forage yields and increased growth of legumes apparently reduced the pH level more rapidly as a result of heavier utilization of calcium.

Irrigation helped to keep Ladino clover in the pasture mixtures.

Applying nitrogen fertilizers to an irrigated field seeded with Ladino clover in the pasture mixture produced only a slight increase in the yields of dry matter.

Nitrogen fertilizer applications tended to reduce the amount of Ladino clover and to increase the amount of grass in stands on treated strips.

Legumes were a more economical source of nitrogen than nitrogen fertilizers.

Soil treatment was as important as irrigation in increasing yields, and a combination of the two gave maximum yields.

For best yields where the phosphate levels are low, the use of additional phosphate is advisable.

Irrigation may be profitable in years of normal rainfall where as few as three irrigations are required.

The advice of engineers should be sought for both source of water and system of irrigation to be employed.

Irrigation may take one of the biggest hazards out of determining the carrying capacity of pastures from year to year.

The statements given above are tentative and may be changed when more data are secured.

By contrast, what happens to pasture without irrigation is indicated in a Washington Bureau press release of July 14, 1953 stating that permanent pasturage in southern Missouri was gone, that a minimum of $8 million worth of chemical fertilizer would be needed if plentiful rain falls soon, and that double that amount will be necessary without rain. It was stated that two or three years of good rains will be needed to build up blighted pastures in Texas.

On July 30, 1953 a St. Louis newspaper photograph of lean cattle on pasture carried the caption, "Not even weeds will grow on this once 'improved' pasture. . . . It was fertilized and seeded

according to the latest and most progressive recommendations. But now the drought has it so dry that nothing will grow and cattle are losing weight, demoralizing the market."

Federal Recognition of Need in Connection With Stabilized Agriculture

The 1938 Year Book of Agriculture of the United States Department of Agriculture states:

> In most of the Great Plains livestock runs on native grass pastures or on the open range during most years, and during much of the year. In most of these areas, however, it is essential that other winter feed and emergency supplies be provided for use during much of the winter and during extremely dry years. Often irrigation offers the only possible method of providing such insurance. The recent drought periods on the Great Plains region, [1934 and 1936] brought very forcibly to the front the need for this type of supplemental irrigation.
>
> Stabilization of agriculture in many parts of the United States could be aided greatly by irrigation of these three types: (1) Supplementing the natural precipitation during dry periods in normally humid areas, (2) watering gardens and small forage patches on dry land farms, and (3) supplementing range livestock feed by growing winter and emergency forage crops.

The *1940 Year Book of Agriculture* further states:

> Wherever irrigation development on the Great Plains is feasible it should be carried out in a way that will permit an integrated use of irrigated and non-irrigated farming land along with grazing land. Such integration would be most desirable on a farm-unit basis, but where this is not possible integration on an area basis should be planned in order that irrigated land may be used as a winter feed base for livestock.
>
> The natural forces influencing Great Plains agriculture are so powerful that here, more than anywhere else, public action seems necessary to assist in effecting the adjustments that are needed to stabilize the agriculture of the region. Among such measures is the development of supplemental irrigation.

The Year Book for 1943 to 1947 emphasizes the increasing value and possibilities of irrigation, especially with the use of the best fertilizers, and with spacing and strains of plants adapted to irrigation.

The Year Book for 1948 devoted some space to irrigated pastures which were then becoming popular.

The last three *Year Books* for 1949, 1950-51, and 1952 were on special subjects not involving irrigation.

"Little Droughts" do the Most Damage

The easily recognized and bad droughts, often many years

apart, do not reduce *average* yearly crop yields so much as the unrecognized *little droughts* do year after year, especially when they occur at critical times in the growth of the plants. The rainfall may appear to be adequate to the layman but the farmer notices that it is poorly distributed. Because it is, he gets year after year only part of the crop he could harvest if he knew that water would be available when he needed it and on that basis could increase the plant population and modify fertilization and general culture.

Hidden drought is the real agricultural threat to eastern United States.

Thus supplemental irrigation and the intensive cultivation, fertilization, large plant population, and high type culture which accompany it can often double crop production year after year, and can prevent crop damage and interruptions of the livestock programs for the occasional easily recognized and bad droughts.

Meteorologists cannot predict when to expect bad droughts; in fact, they cannot even agree on a definition of a bad drought. Every bad drought harms different parts of the farm program differently. Attempts to make rain by cloud seeding as a remedy for bad droughts have not proved successful and they are not even attempted for *little droughts*. No moisture relief is in sight for the farmer except as he himself provides it.

Many believe that summers are getting drier and hotter but, be that as it may, water is undoubtedly getting scarcer due to increased domestic, irrigation, and industrial use. Early irrigators will probably have preference as to the legal rights to use their water.

Fortunately, supplemental irrigation is not designed to relieve these bad droughts only, but also and more importantly to care for the *little droughts*, those *sneak thieves* of agriculture which prevent maximum crops year after year.

Rainfall Deficiency

Most crops in the East suffer in most years from insufficient rainfall at critical times during their growth. Much of the rainfall is not effective since less than one-quarter of an inch may not penetrate the ground sufficiently and since a considerable percentage of the heavier rainfall, of three-quarters of an inch or more, may be lost in percolation or run-off which does not remain in the root zone.

Table I shows the daily rainfall in the central part of the United States during the 3-months summer periods.* Rainfall of less than 0.25 of an inch is omitted as being generally ineffective. Intervals of ten days more without effective rainfall are usually as long as crops should go without water unless the soil is very retentive of moisture. These dry intervals are shown by a heavy black line. They are usually harmful, although not often ruinous. Since several such periods occur nearly every summer, and some may seriously reduce yields, the necessity of added water is obvious. As explained later, this irregular rainfall does not store enough water in the soil for maximum plant growth.

The usual deficiency and irregularity in summer rainfall cause reduced quality and quantity of crop yield year after year, make impossible the cultivation of certain crops which especially need adequate water at certain periods of their growth, and prevent securing the better prices of early, late, or drought markets. Furthermore, since it is thought that many fertilizers tend to *burn out* a crop which is inadequately watered, farmers who must depend on rainfall alone hesitate to use fertilizer intensively enough for maximum yields.

The rainfall records for any particular location may be checked as far back as they are available to note the recurrence of dry years. The local weather forecaster can supply the information and interpret it for those contemplating irrigation. As an example of droughts in one region, one-fourth of the 84 years in Missouri from 1870 through 1953 have been dry and, unfortunately, these dry years have often been close together, causing a ruinous accumulation of losses. As examples, in 1934 followed by 1936 and in 1952 followed by 1953, there were officially declared drought disasters over large parts of the State. Similar histories will be found throughout much of the East. On the contrary, Thornthwaite finds Iowa rainfall distribution more satisfactory.

The data plotting methods of Table I and of References 32 and 41 are both useful, the former qualitatively and the latter for quantitatively scheduling irrigation.

Recent Developments

The experimental stage is past. Among the proved developments of recent years which now make irrigation more

*From the records of the United States Weather Bureau.

Table I.

DISTRIBUTION OF RAINFALL IN INCHES AT JEFFERSON CITY, MISSOURI, DURING JUNE, JULY, AND AUGUST FROM 1934 TO 1953 INCLUSIVE.

Rainfalls less than 0.25 of an inch are omitted and periods of ten days or longer without effective rainfall are shown by heavy dark lines. Irrigation would be needed during these dry periods at a "rule of thumb" rate of 1" per week, or a little more, and occasionally at other times.

		1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953
June	1		0.30									0.29					1.28				0.31
	2		0.50												1.22						
	3	0.39	0.60		0.40		0.40										.48	1.34			
	4				0.82	0.25					0.41										
	5				0.42						0.37				1.20					.30	0.42
	6										1.14						.71				
	7		0.81			0.60		1.54		0.39	0.63		1.20		0.28				.44		
	8									0.54	0.54		2.11								
	9				1.98		0.39		0.55	0.48		0.45					.32		.37		
	10	1.80			1.10	0.49	0.40		0.80	0.62			0.67					.70			
	11	0.41	1.04			2.10		1.10													
	12						0.60	0.54		1.65									1.33		
	13											0.30				.39					
	14																.44				
	15					0.34								0.80		.60	.71		.29		
	16										0.70					.46					
	17		1.09		0.30								0.68								
	18												0.25			1.15					
	19		0.34							0.26				1.18							
	20						0.90												.72		
	21		0.60				0.85			0.40					0.35	2.37	1.08				
	22						0.68			0.56	0.29					1.28				.83	
	23										0.53								.28		
	24							1.25	0.30								.27		1.96		
	25														1.73	.45	1.24				
	26		0.62			0.27				3.63			0.74		0.26	1.31	.36		1.22		0.57
	27									0.45					0.66		.26				
	28								1.88				0.81			.66			.58		
	29		1.05											0.81	0.57				.58		
	30															.56			.51		
July	1			0.25									1.70		0.81						
	2		0.40																		
	3								0.25												
	4										0.27							.26	1.22		
	5									2.58	0.61				0.36						0.29
	6														0.25				1.63		
	7																				
	8					0.62														.60	0.41
	9						0.45		0.84				0.67						.36		
	10									3.20							.80		.33		
	11				0.30				3.30							.74					
	12											0.43							.68		
	13		0.34																		
	14					0.82														.39	
	15																			.54	
	16																.83				
	17				0.43	0.80					0.30						.44	1.10			
	18					1.04												.40			
	19				0.80						0.67							1.37			
	20															1.10					
	21																				
	22		0.65													.60					
	23		0.43														.69				
	24																				
	25										0.37										
	26											1.70				1.95				.52	
	27												0.80	1.58							
	28	0.96				0.30								1.84							
	29																				
	30										0.87	1.20				.28				.48	
	31																				
Aug.	1	0.25									1.86							.88			
	2				0.40		0.35					1.33									
	3									0.45											
	4				0.64					1.10			0.45			.56					
	5									0.51											
	6							1.30						2.02						.49	1.26
	7																				
	8			2.82														.60			
	9							3.00			0.74							.34	.42	1.92	0.26
	10		0.46					0.43													
	11	0.40						0.46									1.27			1.34	
	12	1.05					0.40													.65	
	13		0.25											1.75			.90	1.86			
	14													2.83			.34			.75	
	15									0.81				4.77	0.34				1.97		
	16	1.35		0.58														1.18			
	17	1.30			0.65		0.68														
	18						0.63	2.20												.41	
	19		0.52						0.40				0.47								
	20																1.53				
	21	1.57				0.66						1.21								2.04	
	22				0.25							0.51									
	23						0.55			0.60		0.26									
	24													0.51							
	25								2.15					0.42	0.25						
	26								0.90			1.85							.28		
	27							0.40								1.19			.92		
	28					0.30										.50	1.14		1.60		
	29																		.38		
	30																	.63			
	31																				

attractive in the eastern half of the United States may be mentioned the following:

1. Greatly improved pumps and power, including portable pumping plants and rural electrification. The rural electrification rate for irrigation pumping is about 2 cents per kilowatt-hour, but few of the power lines can carry a heavy pumping load. This lack of capacity is being remedied. A representative of the power supplier should approve any plan for more than a 5-horsepower motor and should check wiring, transformer, and switches.

2. Greatly improved portable pipe systems for carrying water from the pump to the land. A single pumping plant with such a pipe system often can be moved to various locations, thus minimizing the investment cost.

3. Greatly improved portable overhead spraying and rotary sprinkling systems.

4. Greatly improved Thornthwaite methods of knowing *when and how much* to irrigate to secure maximum crops, and how to schedule planting for a pre-determined harvesting date.

5. The construction of large, inexpensive farm ponds that have been and are now being built with governmental aid throughout the eastern part of the United States.

6. Constantly improving rainfall predictions from the Weather Bureau. These materially aid one to decide whether, and when, to irrigate. Without them irrigation may be ruinously delayed because of hope for rain that does not come or may be used harmfully before a heavy rain.

7. Realization that supplemental irrigation is growing in popularity, is practical, and is much cheaper than irrigation in arid regions. No small part of this realization is due to the promotional efforts of manufacturers of irrigation equipment.

8. The increasing interest and experimentation throughout the country as indicated in such publications as those listed in the References of Appendix G at the end of this book. It is now realized that losses due to interruption of the farm and livestock program may equal to losses due to diminished crops. Teachers of agriculture can now spread the ideas.

9. Better markets for early and late crops. Often drainage is improved where surface irrigation is used. This will permit earlier spring planting; will give earlier maturities; and will facilitate farming operations.

10. When acreage restrictions and allotments are imposed, larger yields may be raised per acre.

11. Heavier fertilization.

Requirements for Success

As a better agriculture develops with a correspondingly expensive culture, lack of moisture at the right time becomes the limiting factor in producing maximum crops. With modern high production costs, the farmer must raise maximum crops.

While supplemental irrigation eventually will become widespread, early operators may profit most, since they will have better and more varied crops and more valuable land than their non-irrigating competitors. Also, they will have priority of water rights as mentioned in the next chapter. Often they will raise valuable seed and root stock crops to sell to drought-stricken neighbors.

A war economy with material shortages may delay installation of irrigation. This has been a handicap in recent years. The manufacture and installation of equipment for irrigation projects are among the better ways to stabilize industry and to provide self-liquidating investments for many farmers. Many sprinkling systems are sold on a one-third down payment.

It is essential that each individual installation for supplemental irrigation be recognized as a separate problem that must be studied in all its aspects and developed in accordance with the best modern practices if maximum success is to be attained. Also, community effort must be organized for irrigation. Halfway measures or procedures will not result satisfactorily.

To assist in such studies, development, and organization, the following description of supplemental irrigation will give an idea of the methods generally applicable in the East, but it does not cover all the necessary details and precautions for actual irrigation or the details of crop culture. Teachers of agriculture must furnish the educational background. Additional information may be secured from the references, from irrigation advisers of agricultural colleges or the Soil Conservation Service, from the experiences of others in the East and West, and from personal observations.

CHAPTER II

FAVORABLE CONDITIONS NECESSARY

In order that irrigation may be profitable, it should be limited to suitable soils, to favorable topography, and to land where deep drainage will be unnecessary later. There must be an adequate and economical source of water supply and, of course, a satisfactory market. Maximum crops are obtained with a combination of irrigation, fertilizers, and a variety and spacing of plants adapted to irrigation.

Soils

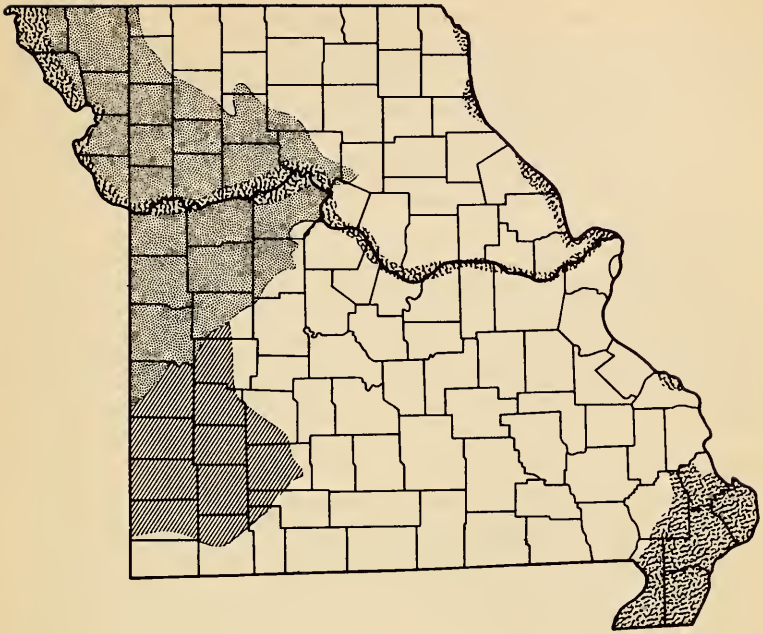
It must be emphasized that good soil is essential. The United States Bureau of Reclamation recognizes six classifications ranging from those lands wholly suitable for irrigation development to those lands having a production so low that they are considered permanently nonarable. Borderline cases between these extremes should be passed on by soil experts.

An ideal soil for irrigation is a medium-textured, highly fertile soil with a subsoil which is only slightly finer-textured than the surface. The most desirable surface textures for irrigation include sandy loam, fine sandy loam, silt loam, and loam. Slightly less desirable surface textures are clay loam, silty clay loam, and loamy sands. The highly organic muck and peat soils can be successfully irrigated. Extremely sandy soils and heavy clay soils often are not well adapted to irrigation.

Rice is not damaged by an excess of water, and the level clay soil areas along the larger southern streams are the most successful rice-producing areas.

Large areas of land, especially on topography which is favorable for irrigation, are often underlaid by a dense, impervious, claypan subsoil which restricts drainage. However, under light and controlled applications of water, and with careful attention to drainage, much of this land may be irrigated successfully.

Bodies of irrigated land vary in size from a few acres up to hundreds of thousands of acres. An example of the location of the larger irrigable areas for one state is shown in Fig. 1. Similar situations exist throughout the East.



Bottomland along the Missouri and Mississippi rivers that probably includes the most desirable irrigable land, because of favorable water, soil, and topographic conditions. Bottomland along the many smaller streams, particularly in the northwestern part of the state, may be equally favorable, and its distribution can be determined by consulting large scale soil maps.

The upland soils of northwestern Missouri are generally of high fertility and good structure, and irrigation will be feasible. Most of the land is rolling and near the larger streams it is hilly, often necessitating sprinkling.

The southwestern prairie section of Missouri includes extensive areas of brown limestone soils and is well suited for the irrigation of orchards, small fruit, and pastures. Higher winds and lower humidity, especially in late summer, add to the need for supplemental irrigation. Ground water in this area is limited and generally surface water supplies will be used.

Fig. 1. General location of the more extensive bodies of irrigable soils in Missouri. For one reason or another parts of these large blocks of land may not be suitable for irrigation. Many other suitable, but smaller areas occur in every part of the State. (Courtesy, H. H. Krusekopf.)

If any doubt exists as to the suitability of the soil for irrigation, a soils adviser should be consulted, bearing in mind that under irrigation the more profitable crop may be entirely different from that grown under rainfall only. For example, irrigation projects constructed on dry-farmed wheat lands and designed for dairying and citrus fruits have later changed to rice and cotton as more profitable.

Topography

For the simpler types of surface irrigation, there should preferably be a slight and uniform ground slope of from 2 to 8 inches or a little more per 100 feet. Flatter and much steeper slopes can be irrigated by the *Special Methods* described on page 69. Sprinkler irrigation can be used on almost all types of topography.

Saline Soils and Drainage

Where large bodies of adjoining lands are irrigated in the arid West, there frequently develops a water-logged or *alkali* condition that requires artificial drainage and other expensive relief measures. Circular *707* of the U. S. Department of Agriculture, Saline Soils, September, 1944, states: "On much of the 20,000,000 acres of farm land now irrigated in 19 western states the crop yields are reduced 10 to 20 per cent by salinity, or an excess of soluble salts in the soils, commonly called alkali. Salinity causes not only a reduction of crop yields but also, if severe, an outright abandonment of irrigated lands."

These conditions should not be encountered in the humid East where irrigation will be light; irrigated areas will be relatively small; heavy rainfall and light evaporation will prevent the accumulation of salts; and ground water levels are not rising.

It is generally better not to irrigate land if it is anticipated that the water table will rise sufficiently to necessitate expensive drainage.

Water Supply

In many seasons a supply of water sufficient to cover the irrigated area to a depth of several inches during the summer will be adequate although for some regions, some crops, and some dry periods, double this amount will be needed. If pumping is necessary, the *lift* from the source to the surface of the land, including friction losses, should usually be less than 75 or 100

feet but may greatly exceed this with cheap power, for large projects where irrigating costs per acre will be low, for valuable crops, for crops requiring little water, or for other special conditions. Pumping will usually be planned for daylight only, perhaps 14 hours daily, but in unusually dry weather the pumps may be run longer hours and for more days.

In western arid regions serious legal difficulties regarding water rights are encountered, but such difficulties should be less serious in the near future in most of the rural East where the water supply is more abundant. In some cases a common-sense judgment will suffice as to whether the consumption of certain waters for irrigation will be harmful to other users. In most cases an irrigation adviser should be consulted as to how to protect the water right. So far as is known, the legal question of water rights for irrigation has seldom been decided in the East, but is of increasing importance. See Reference 33A.

East prospective irrigator should attempt to protect himself so that his use of water will not be taken away from him in the future. Most water laws are increasingly based on *prior use* and on *beneficial use*, both of which tend to favor early users. The older *riparian* theory of surface water will doubtless continue to be modified.

In several states where extensive pumping has been undertaken for irrigation or industrial purposes, the underlying water table has been lowered sufficiently to cause considerable restrictive legislation regarding the use of ground water. Difficulties of this nature may be anticipated in some eastern rural districts in the future. If and when they do develop, the water rights of early users may be given preference.

Markets

Better and closer markets are necessary and, fortunately, more available for the East than for most of the arid irrigated regions of the West. Cooperation must be developed among all those interested in irrigation, both in marketing and in perfecting irrigation practices.

CHAPTER III

SOURCES AND CONVEYANCE OF THE WATER SUPPLY

The first step in irrigation is to locate the water supply and get it to the field.

Gravity Supplies

Under a gravity system the water is taken at a higher elevation, without pumping, from a pond, lake, spring, or stream and conveyed to the irrigated lands by gravity in canals or flumes, as shown in Fig. 7, or through pipes on the surface or underground, all as described in Appendix F. Where gravity supplies are possible, they are often the least expensive method of securing the water.

Farm Ponds

Large multiple-purpose farm ponds are now being advocated and built in considerable numbers throughout the East. Federal aid probably will continue to be available. Since the ponds usually occupy high ground, it will be possible to irrigate by gravity small areas in the valleys below the ponds and thus to secure irrigation water at low cost without pumping. The methods of constructing and using these ponds are described in References 9 and 19, and in many other publications.

When a pond is suitably located, it may also be possible to use it as a reservoir into which a small low-cost pump continuously discharges sufficient water to permit the irrigation of a much larger area than could be watered from the pond alone. The advantages of this pondage over using a small pump without a reservoir are that rainfall is stored and used; that cheap pumping results from running the pump 24 hours per day, as described later; and that the irrigator may irrigate by daylight and does not waste his time in using only the small flow of water discharged by the pump. Furthermore, this pumped well often will supply a safe domestic water, while pond water for that purpose requires filtering and chlorinating.

Such benefits from the farm pond may justify its construction or may suggest a different size and location for the pond.

Example of a Small Farmstead Pond

A small circular pond with a bottom diameter of 44 feet, side slopes of 3 to 1, a top diameter of 116 feet, and a maximum depth of 12 feet will hold one and one-half acre feet of water. In the Middlewest such a pond will fill from a drainage area or catchment area of about 8 acres in a drought year, and of course will fill more than once in a year of usual rainfall. It will cost about $225 or $150 per acre-foot stored.

Since considerable evaporation and seepage occur, possibly only half of this water will reach the land to be irrigated. This will irrigate about an acre in a dry year and, of course, more in an ordinary year. This might be sufficient for some livestock, garden truck, and a lawn.

To irrigate more acres a pump could discharge about 5 gallons per minute into the pond continuously through much of the summer and this would irrigate another acre or two in a dry year.

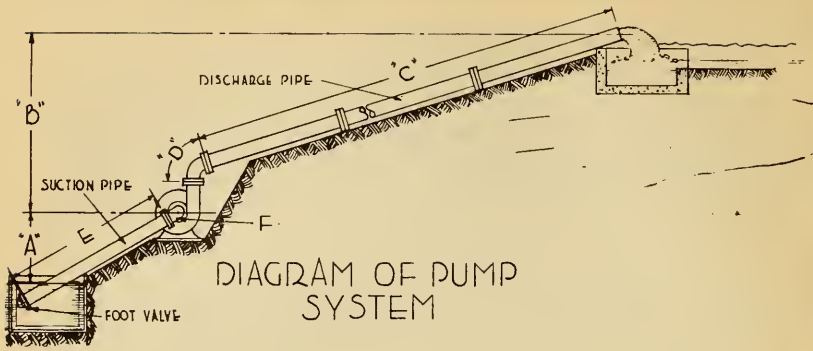
Since the irrigating water would be drawn from the pond as a reservoir, a stream sufficiently large to keep the irrigator busy could be used in daylight. A pump could also furnish a more than adequate domestic water supply for the home, lawn, garden, and barn. If directly connected to the pump, no filter will be needed for the domestic supply and perhaps no chlorination will be needed since the well water can be pumped directly from the well into the home tank.

Much larger ponds, pumps, drainage areas, and irrigated areas can be used and the quantities of the four will vary nearly in proportion, except that the cost per acre-foot stored will be less. For example, that cost will be about $50 for a pond holding 40 acre-feet.

The larger pump will not be necessary for the domestic supply, in fact, the 5-gallon-per-minute pump would be run only occasionally for the domestic supply. Most of the multiple benefits of the farm pond would continue to be realized.

Pumping from Open Water

Next in economy of securing the water are those supplies pumped from rivers, creeks, or lakes, typical layouts for which are shown in Figs. 2, 22, and 26. Gasoline engines, Diesel engines, and electric motors are available as sources of power. Automobile or tractor engines have been used but have seldom given the best results. While any type of pump may serve, centrifugal pumps



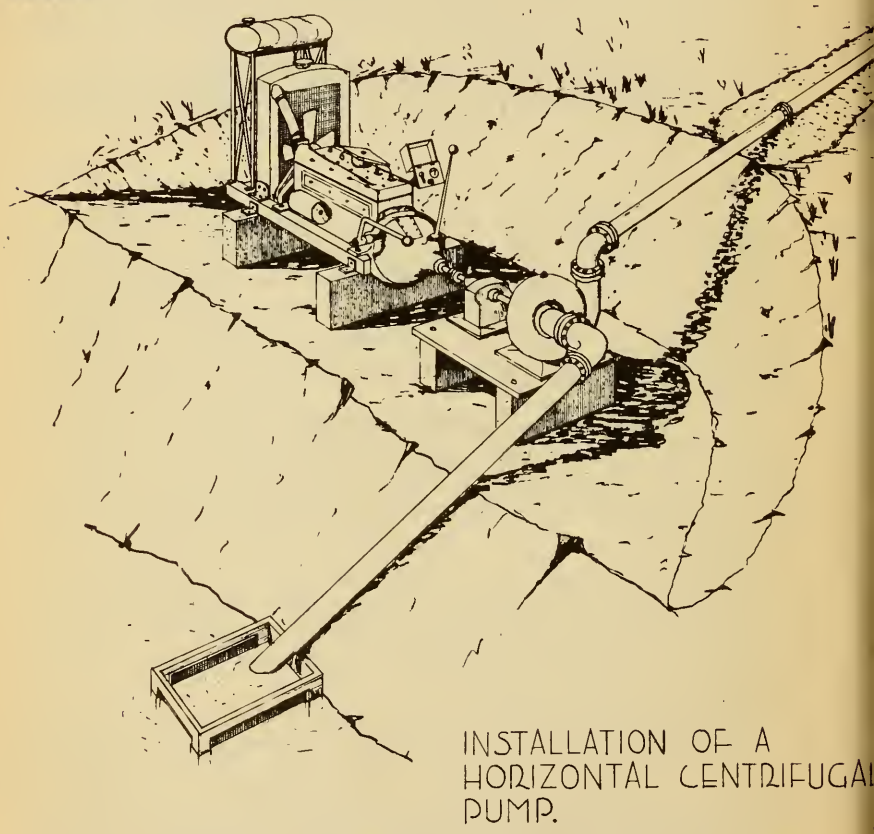
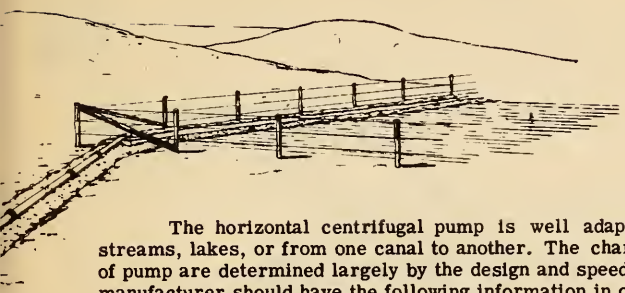


Fig. 2. Pumping from open water. More modern direct-connected pumping units are now available as shown in Fig. 26. (Courtesy, U. S. Farm Security Administration.)



The horizontal centrifugal pump is well adapted to pumping from streams, lakes, or from one canal to another. The characteristics of this type of pump are determined largely by the design and speed of the impeller. The manufacturer should have the following information in order to furnish a pump which will give the best efficiency under given conditions:

1. The quantity of water desired in gallons per minute or cubic feet per second.
2. The total "head" or lift in feet.
3. The type of power available and probable speed at which the pump will operate.

The total "lift" or "head" includes not only the actual vertical distance in feet to which water must be lifted as A+B in the sketch but also the friction head in the pipe and pipe fittings.

The size of the suction and discharge pipe must be adapted to the quantity of water to be pumped. The table below indicates the lost head due to friction per 100 feet of length as well as the losses through pipe fittings in terms of equivalent lengths of pipe.

FRICTION LOSS PER 100 FEET OF COMMON USED PIPE AND LOSS DUE TO FITTINGS

GALLONS PER MINUTE	DIAMETER OF PIPE				
	4-IN.	5-IN.	6-IN.	8-IN	10-IN.
	FRICTION HEAD IN FEET				
400	15.82	5.33	2.21	0.56	-----
450	19.75	6.65	2.74	0.64	0.21
500	24.08	8.12	3.26	0.81	0.28
750	-----	17.22	7.00	1.74	0.59
1,000	-----	-----	12.04	3.02	1.01
1,250	-----	-----	18.20	4.45	1.51
1,500	-----	-----	-----	6.27	2.09
2,000	-----	-----	-----	10.71	3.50
FRICTION LOSSES THRU PIPE FITTINGS IN TERMS OF EQUIVALENT LENGTHS OF PIPE					
GATE VALVE	3.44	4.57	5.72	8.10	10.70
MEDIUM SWEEP ELBOW	5.77	7.68	9.61	13.60	17.97
STND ELBOW	9.22	12.20	15.30	21.71	28.70

An example: (See sketch)

Let A+B = 20 feet actual head.
Let C+E = 200 feet actual length of 8-inch discharge and suction pipe
D = Medium sweep elbow equivalent to 13.6 feet of 8-inch pipe.
F = Standard elbow equivalent to 21.7 feet of 8-inch pipe.

Compute total head when pump is delivering 1000 gallons per minute.

An 8-inch pipe has 3.02 feet of friction head for 100 feet of length when carrying 1000 gal. per minute. Total friction head in pipe and elbows is (200+13.6+21.7) x .030 or 7.05 ft. Total head is 7.05 feet friction head +20 ft. Actual head = 27.05 feet.

There is a slight additional loss due to the foot valve and other factors.

Friction loss table based on common used pipe.

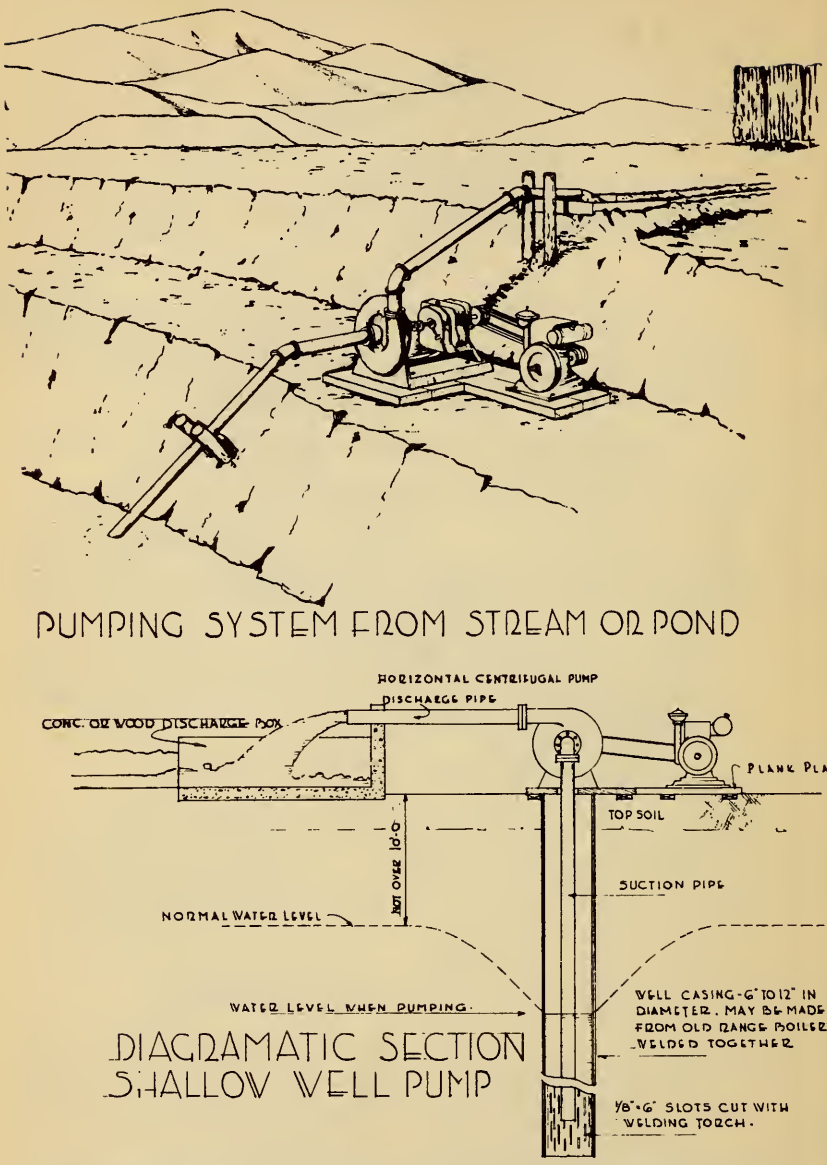
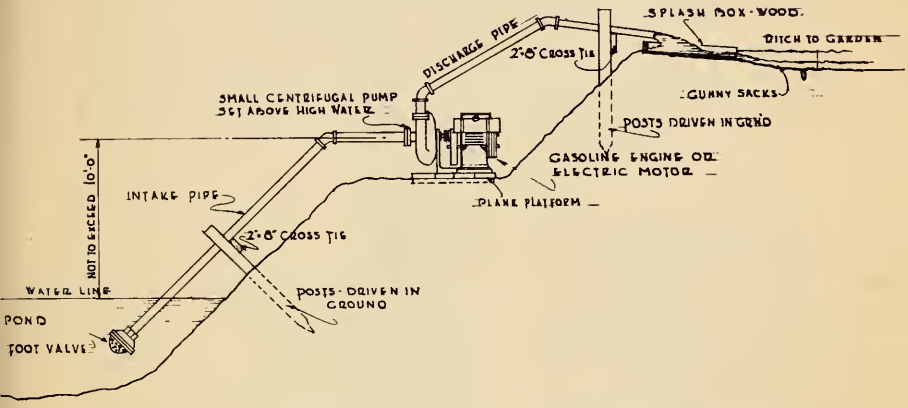

PUMPING SYSTEM FROM STREAM OR POND
HORIZONTAL CENTRIFUGAL PUMP
DISCHARGE PIPE
CONC. OR WOOD DISCHARGE BOX
PLANK PLATFO
TOP SOIL
SUCTION PIPE
NOT OVER 10-0
NORMAL WATER LEVEL
WATER LEVEL WHEN PUMPING
WELL CASING-6" TO 12" IN DIAMETER. MAY BE MADE FROM OLD RANGE BOILERS WELDED TOGETHER
DIAGRAMATIC SECTION SHALLOW WELL PUMP
1/8"-6" SLOTS CUT WITH WELDING TORCH.

Fig. 3. Pumping from open water and open wells. More modern direct-connected pumping units are now available as shown in Fig. 26. (Courtesy, U. S. Farm Security Administration.)



DIAGRAMATIC SECTION OF PUMP SYSTEM FROM STREAM OR POND

Pumping from a stream or pond

Garden irrigation can be accomplished by pumping from ponds and streams if the lift is not too great. A small horizontal centrifugal pump set not higher than 10 feet above the water and powered by a gasoline engine in the equipment ordinarily used. Pumps of this type may be had in sizes which will deliver from 30 to 1000 gallons or more per minute.

Pumping from shallow irrigation wells

Along river bottoms where the ground water level is permanently within 10 feet or less from the surface, small irrigation wells may be successfully used for the irrigation of farm gardens. Casings for such wells are ordinarily made from sheet metal slotted to permit water to enter. In some instances old range boilers with the ends cut out are welded together and slotted with a welding torch. Small centrifugal pumps set at the ground surface are quite satisfactory.

Fig. 3 Continued.

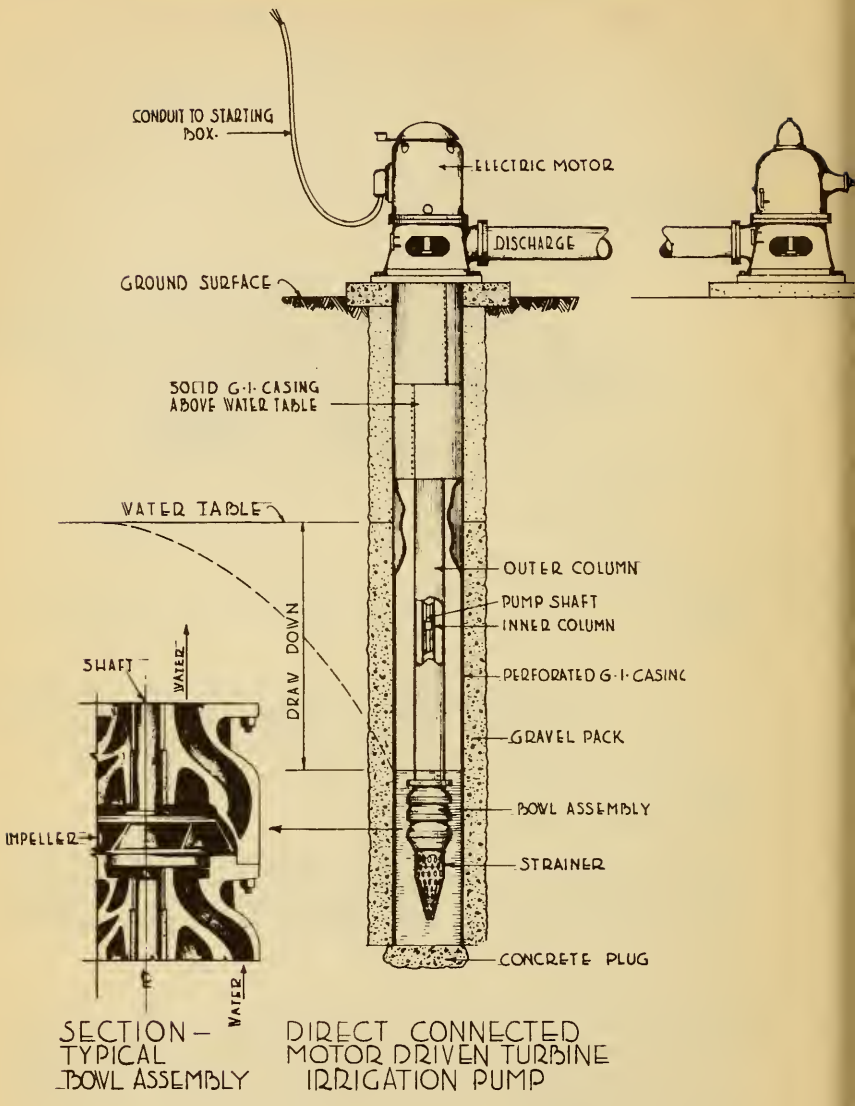
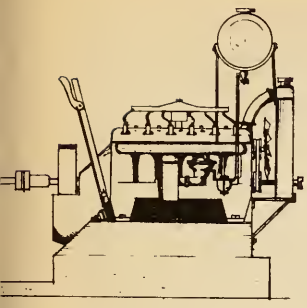
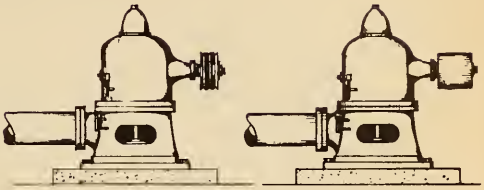


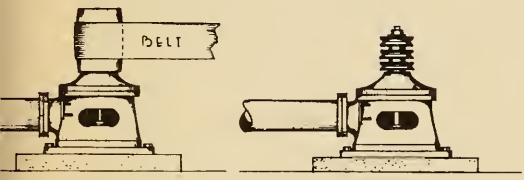
Fig. 4. Pumping from wells by turbine and propeller pumps. (Courtesy, U. S. Farm Security Administration.)



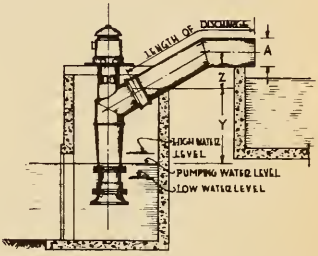
RBINE TYPE IRRIGATION PUMP WITH
AR HEAD CONNECTED TO A POWER
IT WITH A SHAFT AND DOUBLE
IVERSAL JOINT.



IRRIGATION PUMP GEAR
HEAD WITH EITHER V-BELT
OR FLAT-BELT DRIVE PULLEY.



TURBINE TYPE IRRIGATION PUMP
WITH HEAVY DUTY BELTED HEAD
FOR EITHER FLAT OR V-TYPE BELTS.



PROPELLER TYPE
IRRIGATION PUMP

TURBINE AND PROPELLER TYPE IRRIGATION PUMPS

The turbine type irrigation pump is adapted to lifting water from ells of various diameters and through various heads from a few feet o several hundred feet. The characteristics of the pump are determined rgely by the design of the bowl assembly and the speed of the impeller haft.

In order to determine the type of pump and design of bowl as-embly required for the best efficiency under given conditions the manu-acturer should have the following information:

1. The discharge of the well at various stages of "Draw Down". This is determined by a pump test of the well.
2. The diameter of the well casing.
3. The type of power to be used for driving the pump.

Where three phase electrical energy is available, the direct con-ected motor drive may be used. Other types of drives for the turbine ump are shown.

The propeller type pump is adapted to lifting large volumes of ater through low heads. In irrigation practice it is used to deliver ater from a stream or lake to a canal at higher level or from a low evel canal to one at a higher level. The same types of drives as shown or the turbine are adapted to the propeller pump.

are best in most cases. A pumping plant may be located permanently or it may be moved from one location to another as circumstances require. It is seldom satisfactory if bought second-hand because it may not fit the new requirements.

Pumping from Wells

Somewhat more expensive water supplies are obtained with deep-well turbine or centrifugal pumps using open wells, drilled wells, bored wells, or well points driven into the water-bearing strata. Figures 3 and 4 show typical set-ups of this kind. The deeper and larger wells are often gravel packed.

Selection of the Pump

Unless the presence of plentiful water has been clearly demonstrated in the neighborhood, one should write the state geologist for information as to depth, quality, and quantity of water available. A reliable local well driller should be employed to put down the wells. The level of the water is usually lowered materially by pumping and this *drawdown* must be considered in selecting the pump. Wells should always be tested to determine their elevation after drawdown and their potential capacity before selecting the power plant and pump.

The pumping *lift* used in selecting the pump must include the drawdown of the well, the vertical lift from the normal water surface, the friction loss in all pipes, elbows and valves, and the entrance and discharge losses. Fig. 2 shows the method of computing the total *head* or lift. For sprinkling systems, nozzle pressures and losses in distribution pipes must be added. It is helpful if a community can standardize its pumping equipment so that stock parts and service may be available locally.

The selection of the pump and the motor or engine to run it is a highly technical matter and must be left to a reliable pump and irrigation adviser in order that a coordinated system of motor or engine, pump, water conveyance, water application, and crop diversification may be secured. While advice, perhaps even a guarantee, is essential in a sprinkling layout, it is almost as necessary for surface irrigation, although not so obviously so.

It is recommended that a formal agreement be drawn up between the purchaser and the irrigation supply or pump company specifically listing the equipment and accessories to be furnished by both parties, the guaranteed performance of the irrigation system or pump, the provision for testing the perform-

ance, and the method of payment to the company, somewhat after the manner of pages 84 to 87.

Pumps of smaller capacity that run constantly are cheaper in first cost than large pumps that run intermittently. Furthermore, the drawdown in wells will probably be less for the smaller pump and the total lift of water will be reduced, thus lowering pumping costs. If electric power is used, the power rate may be lower for the more continuous operation. On the other hand, smaller pumps are slightly less efficient and more irrigating labor is usually required.

The technical details of pumping are discussed further in Appendix C, and in many of the References.

If sprinkling is used, provision may occasionally be necessary for removing debris and silt from the water since otherwise the nozzles are easily plugged and both bearings and nozzles wear rapidly if silt enters the lines. A suitable screening and desilting box is described in Appendix D and also on pages 29 and 30 of Reference 210 and in Reference 214.

City Water Supplies

Cheapest in first cost but more expensive in operating cost are those water supplies obtained from city water mains. The high cost of this water is justified only for the most expensive crops, as for example, truck gardens, fruit trees, shrubbery, or lawns. In dry periods cities often restrict the use of water for irrigation.

Conveyance of Water From the Source to the Land to be Irrigated

The least expensive method of conveying the water is by permanent or temporary canals or ditches (Figs. 5, 6, 12, and 16), but there is considerable loss of water from them; they occupy a considerable amount of land; and there is also trouble from weeds. They are economically constructed by homemade ditchers such as those shown in Figs. 6 and 11, and by manufactured earthmoving equipment. Modern practice demands plowing in most ditches each year to destroy insects, vermin, and weeds.

Less wasteful of land and water but more expensive in original cost are the portable pipes mentioned below, and metal or wooden flumes, the latter shown in Figs. 7, 42, 43, and 44.

The most expensive method of conveyance is in underground pipes, but it has the advantages of minimizing the interference with farm operations and minimizing the loss of water. These are important considerations where land is expensive and water is scarce or expensive, such as that secured from a city main.

One of the important developments of recent years is the use of 20-, 30-, and 40-foot lengths of light-weight portable aluminum pipe with special couplings which permit the pipe to be quickly assembled, dismantled, and moved to a new location on the surface of the ground. This is especially useful in portable irrigation plants where the pipe is laid quickly over the ground, then dismantled and moved to another tract of land by one or two men. Figure 18 shows light-weight pipe with rapid action couplings, several types of which are made by different manufacturers. The couplings are flexible so that the pipe can follow ground irregularities. The same pump and pipe can be used on different parts of a farm or on several different farms, thus minimizing the necessary investment.

Canals and ditches, flumes, and pipes will necessarily be used to some extent in different installations for supplemental irrigation, but it will be optional throughout most of a particular system to select one or the other of these devices for conveying water.

Appendix F will be helpful in considering the various methods of conveying water. The details are omitted here since they often are unnecessary for supplemental irrigation; since they are technical; and since many readers will not be interested.

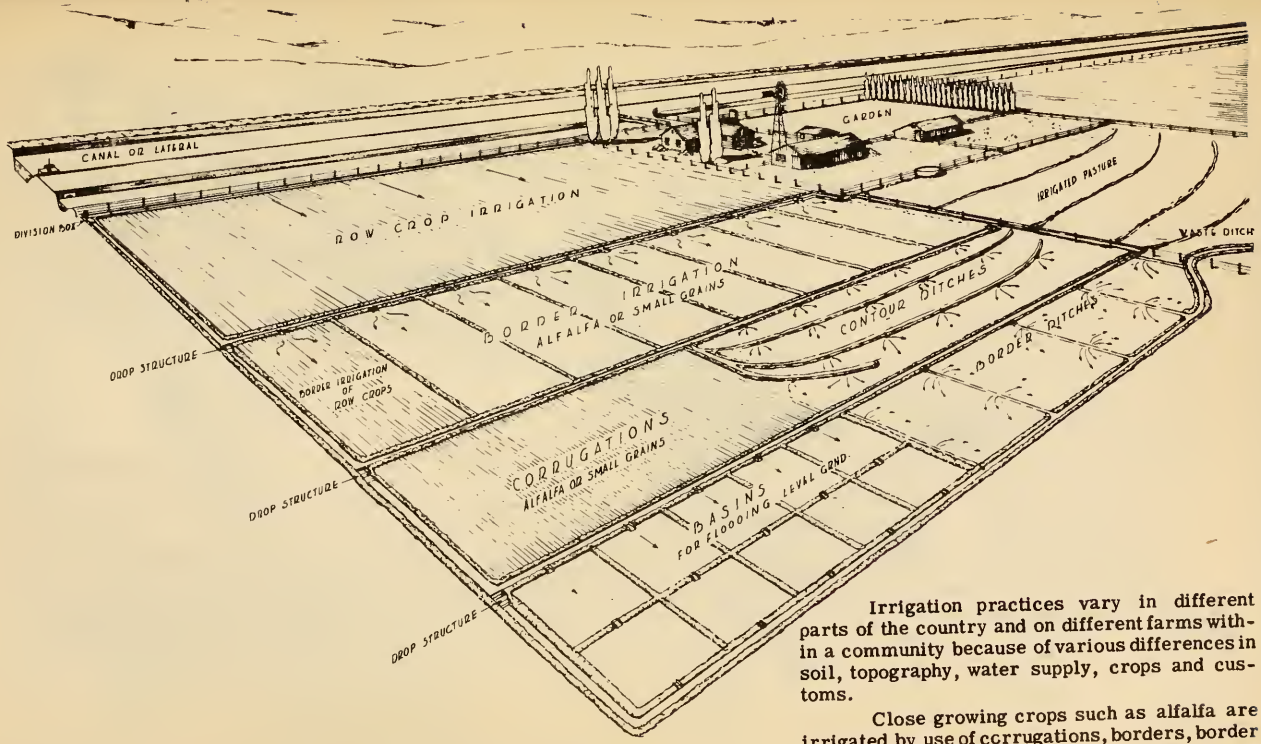


Fig. 5. General layout of an irrigated farm. (Courtesy, U. S. Farm Security Administration.)

Irrigation practices vary in different parts of the country and on different farms within a community because of various differences in soil, topography, water supply, crops and customs.

Close growing crops such as alfalfa are irrigated by use of corrugations, borders, border ditches, basins, and contour ditches while row crops are irrigated by furrows and borders. Any one or a combination of several may be best suited to an individual farm.

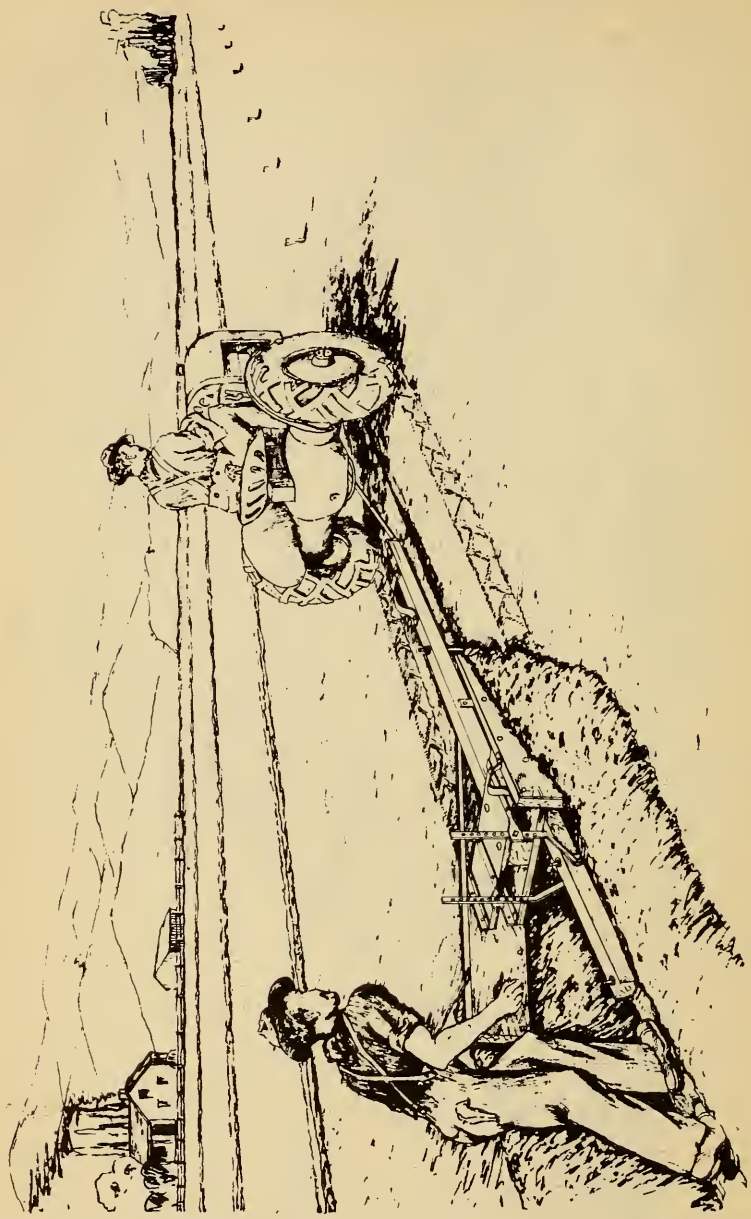
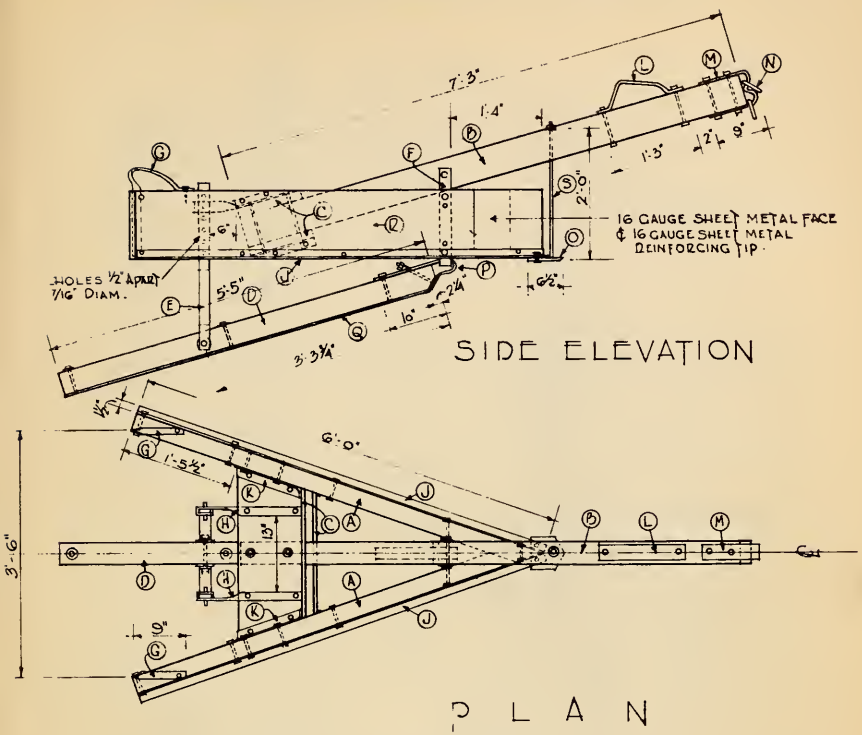


Fig. 6. Irrigation ditcher. (Courtesy, U. S. Farm Security Administration.)



BILL OF MATERIAL FOR IRRIGATION DITCHER

WOOD

- (A) 2 - 3" × 12" × 6'-0" BRIDGE PLANK - (SIDES)
- (B) 1 - 4" × 6" × 8'-0" HICKORY OR OAK - (TONGUE)
- (C)(C) 2 - 2" × 12" × 2'-6" PINE SPREADERS
- (D) 1 - 4" × 4" × 6'-0" HICKORY OR OAK - (SKID)

IRON

- (E) 2 - ½" × 1½" × 3'-0" STRAP IRON (HEIGHT ADJUSTERS)
- (F) 1 - ½" × 2" × 3'-4" STRAP IRON (SKID SUPPORT)
- (G)(G) 2 - ½" × 1½" × 2'-0" STRAP IRON (HANDLES)
- (H)(H) 2 - ½" × 1½" × 1'-9" STRAP IRON (HEIGHT ADJUSTER CHECKS)
- (J)(J) 2 - ½" × 1½" × 6'-0" ANGLE IRON (SIDE SHOES)
- (K)(K) 4 - ½" × 1½" × 1'-0" ANGLE IRON (SPREADER SUPPORTS)
- (L) 1 - ½" × 2½" × 1'-8" STRAP IRON
- (M) 1 - ½" × 2½" × 2'-6" STRAP IRON (CLEVIS)
- (N) 2 - ⅜" × 4" DIAM. RINGS (CLEVIS)
- (O) 1 - ⅜" × 5" × 6½" FLAT PLATE
- (P) 1 - ½" × 2" × 1'-8" STRAP IRON (SKID CLEVIS)
- (Q) 1 - ⅜" × 4" × 5'-6" STRAP IRON (SKID SHOE)
- (R) 2 - 12" × 6'-0" # 16 GAUGE GALV. IRON (SIDE PROTECTION)
- 1 - 12" × 2'-0" # 16 GAUGE REINFORCING TIP.

BOLTS

- (S) 1 - ¾" × 24"
- 2 - 5/16" × 1½" "U" PIECE ELEVATOR (E)
- 2 - 5/16" × 7" TONGUE CLEVIS (M) TO (B)
- 2 - ⅜" × 7" TONGUE SKID (L) TO (D)
- 2 - ⅜" × 9¾" - TONGUE TO CROSSBOARDS (C)
- 4 - 5/16" × 3" ELEVATOR GUIDES (E) TO CROSSBOARDS (C)
- 8 - ¼" × 2¼" - ANGLE IRON (K) TO CROSSBOARDS (C)
- 10 - ¼" × 3¼" - 8 FROM ANGLE IRON (K) TO BEAM (A)
  2 FOR TOP BOLTS IN HANDLES
- 4 - ⅜" × 4½" - BOTTOM SKID (Q) TO BEAM (D)
- 6 - ⅜" × 3½" - ANGLE IRON (J) TO BEAM (A)
- 2 - ⅜" × 1" - TRIANGULAR PLATE (O) TO ANGLE IRON (J)
- 4 - ⅜" × 4" - FRONT "U" IRON (F) TO BEAM (A)
- 1 - ⅜" × 6" - FRONT "U" IRON (F) TO TONGUE (B)
- 2 - ⅜" × 12" - COLLAR TIE FOR BEAMS (A)
- 1 - ⅜" × 5" - "U" PIECE ELEVATOR (E) TO SKID (D)
- 2 - ⅜" × 2" - LAG SCREWS FOR HANDLES.

WASHERS

16 FOR ¼" BOLTS
4 FOR 5/16" BOLTS
18 FOR ⅜" BOLTS

NAILS

APPROXIMATELY 100 - 8 PENNY WIRE
6 - LARGE SPIKES.

Fig. 6 Continued.

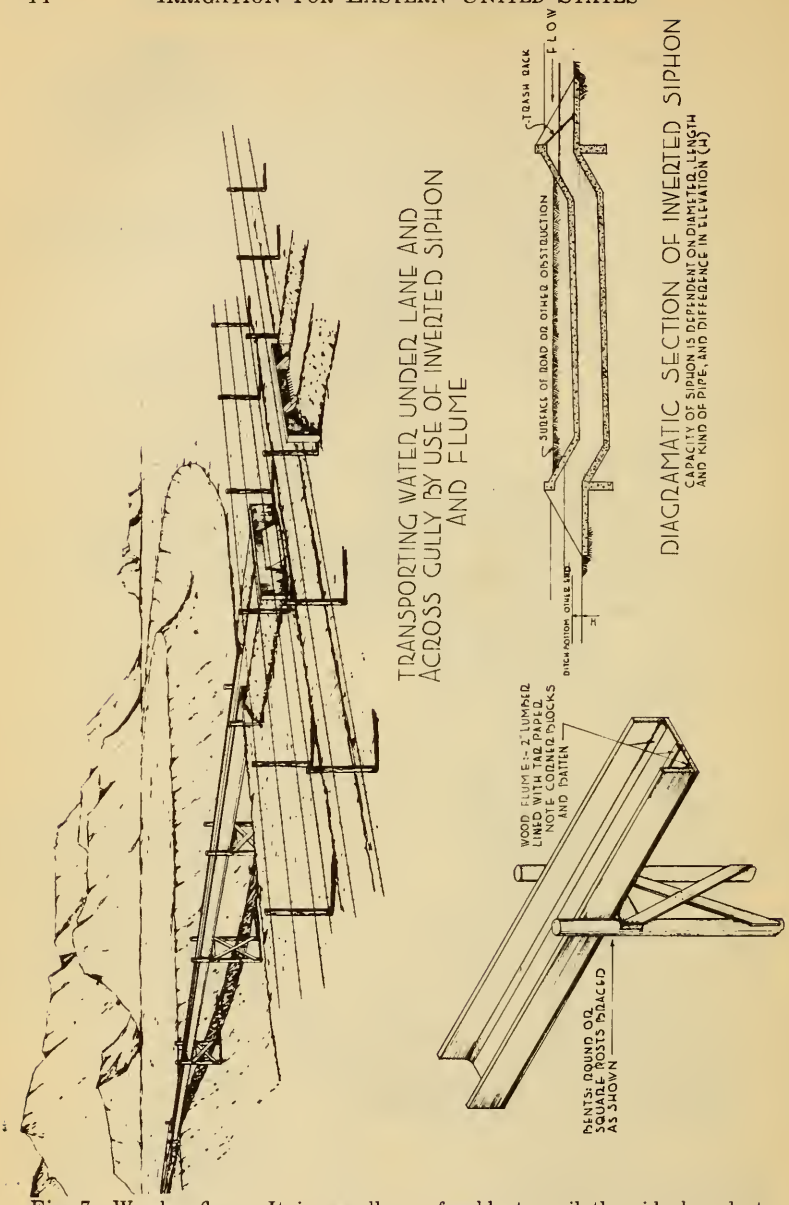

TRANSPORTING WATER UNDER LANE AND ACROSS GULLY BY USE OF INVERTED SIPHON AND FLUME
DIAGRAMATIC SECTION OF INVERTED SIPHON
CAPACITY OF SIPHON IS DEPENDENT ON DIAMETER, LENGTH AND KIND OF PIPE, AND DIFFERENCE IN ELEVATION (H)
FLOW
TRASH RACK
SURFACE OF ROAD OR OTHER OBSTRUCTION
DITCH BOTTOM GRADE LINE
H
WOOD FLUME:- 2" LUMBER LINED WITH TAR PAPER NOTE CORNER BLOCKS AND BATTEN
POSTS: ROUND OR SQUARE POSTS BRACED AS SHOWN
FLUME SECTION

Fig. 7. Wooden flume. It is usually preferable to nail the side boards to the sides of the bottom board. (Courtesy, U. S. Farm Security Administration.)

CHAPTER IV

METHODS OF APPLYING WATER TO THE LAND

In growing bigger and better crops, the plant characteristics of greatest importance in irrigation are the depth of plant rooting habits and the soil-water storage available to the plants.

Water-Soil-Plant Relations

Water is essential in the growth of plants chiefly as a solvent and carrier of plant nutrients. While a small part of the water remains in the plant, most of the moisture taken from the soil passes through the plant and is transpired (breathed) into the air. The amount of this transpiration during a growing season depends on the kind of crop; the thickness of the stand; the soil fertility; the temperature, the humidity, and the wind; and the amount of water the plant can get. The rate of transpiration is almost nothing when water is not available and for young or mature plants in cool, cloudy, weather; but it may reach a maximum equivalent to 2 inches of water over the land per week for rapidly growing, leafy crops during the peak of a drought season when hot, dry winds prevail and when irrigation has furnished adequate water.

A drought resistant crop is one that can slow up its transpiration and other growth functions when water is not available and start up again when water can be secured, as for example the heavy water user, alfalfa.

On the other hand corn uses less water than alfalfa but can be very seriously injured by a comparatively brief dry spell at the critical time of full bloom, or tasseling.

Water Storage in Soils

The maximum amount of water storage available to the plants is that in the upper one and one-half foot to four feet of soil through which the particular plant or crop extends its roots. Often when establishing new crops, only the top few inches of soil need moisture. Most crops depend mainly on their roots in the top few feet of soil although vigorous trees and alfalfa root six feet or deeper. These root-zone depths vary with the types

of soil and subsoil, depths of water table, the kinds of crops grown, and the irrigating practices. The moral from these facts is to supplement rainfall for most crops only with enough irrigation water to fill the upper few feet of the soil, since more simply percolates below the main root zone or runs off the surface. The crops will then tend to root shallow and to benefit most from heavy fertilizer applications which stay mainly in the upper soil zone.

On the contrary, deep root zones are desirable where soil conditions and water supply permit deep penetration and retention since greater supplies of nutrients can be reached; more water can be stored; fewer irrigations will be required; and less water will be lost by evaporation. Each extra irrigation costs labor and money.

Another factor affecting storage is the nature of the soil. Open gravelly sands have little water storage capacity, and irrigation or rainfall percolates rapidly below the root zone. Clay soils retain the greatest amount of moisture but the water *infiltrates* (penetrates) the soil very slowly.

The *infiltration rate* in inches per hour varies from 0.0 for tight clays and clayey silt loam to as much as 5.0 for gravelly silt loam. These infiltration rates govern the maximum rate at which an irrigation may be applied if surface run-off and erosion are to be avoided. The usual maximums for irrigation on level ground are between ¼ inch for heavy soils and 1¼ inches per hour for light soils. They are better observed on the particular soil being irrigated, or under rainfall, than determined from theory or experiment. The allowable rates increase with the amount of cover; diminish as the slope of the land increases; and vary with the elapsed time after a rain or irrigation.

Root systems tend to develop in the areas where nutrients and moisture are most readily available. Dr. C. W. Thornthwaite (Reference 32) states, "Plants tend to be deeply rooted in light or sandy soils which have low water storage capacities and shallow rooted in heavy soils with high moisture storage capacities. This fact may explain in part the phenomenon that regardless of its texture the *soil reservoir* contains only about four inches of water on which plants can draw. This is the amount of moisture that is available to the vegetation in the intervals between rains."

The foregoing root-zone and soil-nature factors govern the

water available to the plant. If little or none is available the plant wilts, if the maximum storage capacity is exceeded the water gets away. The ideal of irrigation is to keep the storage safely between these limits. The methods of determining the water content at a particular time and of deciding when to irrigate are discussed on pages 89 to 93.

Control of Water

Supplemental irrigation is a scientific and somewhat expensive method of growing much larger crops and securing much greater profits year after year regardless of rainfall deficiencies or irregularities. For economical and efficient use of water to this end, the irrigator must have complete control at all times. Uncontrolled streams of water cause inefficiency, waste, and uneven distribution that prevent complete success. They may, rarely, create expensive damage claims. Proper methods save hard and expensive physical labor and assure uniform and satisfactory results. A proper control of irrigating water can improve the yield as much as 100 percent over inefficient methods. Makeshift devices and procedures may be worse than useless. Expert advice is essential.

Many methods of applying water for irrigation, most of which are shown in Figs. 5 and onward throughout the book, have been developed by long experience and consequently will give satisfactory results. Departure from these proved techniques should be attempted only by experienced irrigators. The simplest and surest methods for conditions in most of the East are described and illustrated in Chapters V and VI. They may be studied in more detail in References 1, 7, 10, 18, 20, 21, 28, 53 to 56 inclusive, 102, 151 to 159 inclusive, 201 to 219 inclusive, and in Appendixes D, E, and F. Extensive local experience may develop improvements or adaptations.

Surface Methods Versus Sprinkling

Water may be applied to land by surface methods or by sprinkling, either method being satisfactory if properly used. Sometimes one and sometimes the other method will be preferable. Sprinkling predominates in the East and surface methods in the West. Sprinkling can be used almost everywhere, but surface methods require expert irrigators and suitable topography and soils.

Each method has stout advocates who can see only that method as desirable, and minor advantages or disadvantages are over-emphasized by these advocates. Actually each is better suited to certain conditions that should be carefully evaluated by the farmer and his expert. One of the more important questions is whether the farmer would prefer to invest cash for a complete sprinkler system at the outset rather than to use farm labor and equipment over a few years while perfecting his surface system.

Since the relative first cost and the operating or annual cost of sprinkling and surface methods (and whether they require cash, or labor and equipment use) will partly determine which is used, these costs will now be discussed. For a particular farm, estimates for sprinkling can be secured from dealers and distributors, but estimates for ground methods should be made by an experienced adviser.

Comparative Costs of Surface Versus Sprinkler Supplemental Irrigation

While each installation for irrigation differs from others and though prices and costs rise and fall, an instructive comparison of the costs of these two methods of irrigating is possible. For this purpose a typical eighty-acre tract is shown in Fig. 8 (from Reference 210) as it would be irrigated in the East by semi-portable sprinkling, and the cost of sprinkling is compared with that of surface irrigation on the same tract of land. It is assumed that the topography and soil are reasonably adapted to surface methods and that skilled surface irrigators are not available.

In this example, as is often the case, the total annual costs for each of the methods will be about the same ($20 per acre for average crops in an average year, not including the cost of the well or other water source), and the choice of the one to use will depend often on the other factors discussed in the following several paragraphs and the next two chapters. It must be reiterated that each irrigation installation is different and the cost comparison may be quite different on another tract of land.

Original Costs (Excluding Well or Water Source)

In this example, and usually, it will be noted that sprinkling costs more to install at the beginning than do surface methods.

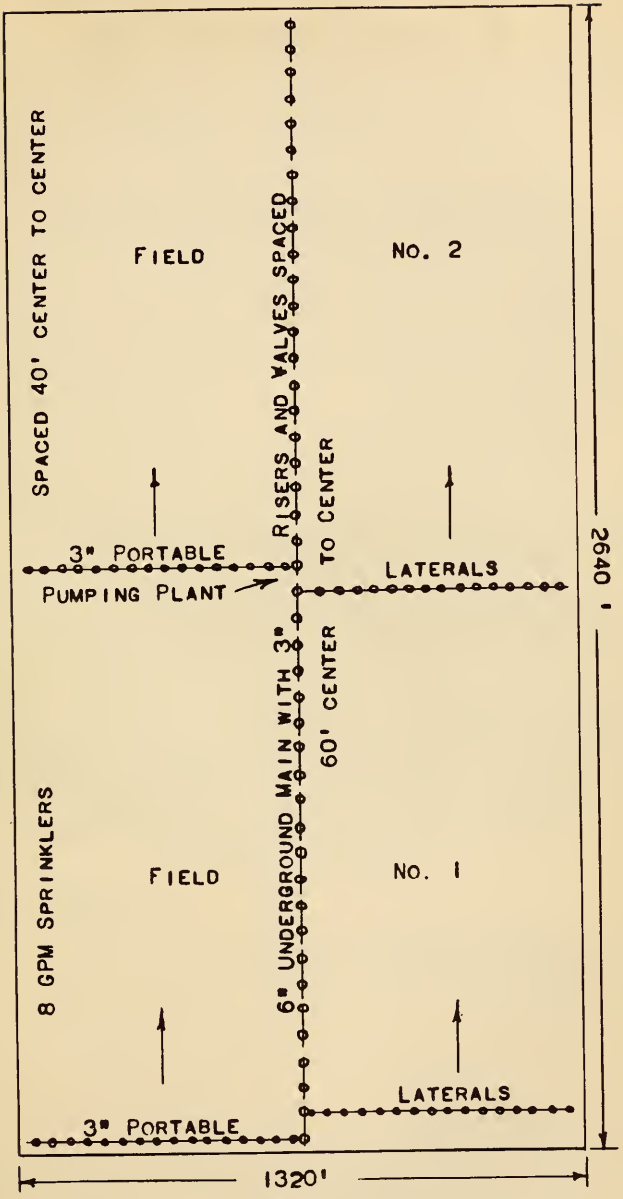


Fig. 8. Example of an 80-acre semi-portable rotary sprinkler system. (From Reference 210, U. S. Bureau of Reclamation.)

Original Costs for Sprinkling Eighty Acres

Well or water source, cost not included	$ 0
Underground mains	4,000
Laterals	2,500
Electric motor, pump, and accessories	1,500
$100 per acre—Total	$8,000

Original Costs for Surface Irrigation of Eighty Acres

Well or water source, cost not included	$ 0
Leveling (smoothing rather than heavy grading)	3,200
Field ditches	1,000
Drainage ditches	100
Combination concrete checks and drops	100
Turnouts	100
Concrete checks	100
Irrigation spiles or tubes	100
15" concrete pipe for roadways	100
Electric motor, pump, and accessories	1,200
$75 per acre—Total	$6,000

Total Annual Costs (Excluding Well or Water Source)

It will be noted in the following tabulation, as is usually true, that the costs per year for interest, depreciation, taxes, insurance, and power are higher for sprinkling, while the labor costs for applying water and for maintenance are higher for surface irrigation unless skilled irrigators are available and unless topography and soil are well adapted to the latter. Interest is charged at 5% on the unamortised balance or 3% on the original cost. There is less depreciation when surface methods are used. Power costs are, of course, higher for sprinkling.

Comparison of Total Annual Costs Per Acre by Sprinkler and Surface Methods

	Sprinkling	Surface Irrigation
Interest, depreciation, taxes, and insurance (cost of well or water source excluded)	$10	$ 6
Labor applying water	4	7*
Power	4	1
Maintenance	2	6*
Totals	$20	$20

General Cost Factors

Most of the original cost and of the annual cost for sprinkling requires a cash outlay, while most of these costs for surface

*With unskilled surface irrigators.

irrigation consist of labor and the use of farm equipment which may require relatively little cash. On the other hand, labor must be much more experienced and skilled in surface irrigation than is necessary for sprinkling.

In the East, pumping usually will be required for both methods. The pumping for sprinkling will be against higher pressures and the power costs greater. However, the original cost of the well, pump, and accessories will not be proportionately increased. When a pump must be furnished and operated for either surface or sprinkler irrigation, this fact favors the latter.

It must be reiterated that the foregoing cost comparisons apply to a particular piece of land. They may be quite different on another tract of land.

Relative Skills Necessary

The application of water by sprinkling is relatively a simple and easily learned science while surface methods are more of an art that may be acquired by those with aptitude and long experience.

For this reason, sprinkling is more suitable for isolated installations or new districts, where no neighbors or advisers are available to teach surface methods or where sprinkling predominates.

On the other hand, surface methods may be suitable where skilled surface irrigation advice is available or where a community largely practices surface methods.

CHAPTER V

SURFACE IRRIGATION

Where topography and soil are favorable, skilled irrigators are obtainable, no pumping is required, and labor and farm equipment are more available than cash, or where most of these conditions exist, surface irrigation will probably be preferable. Often the surface irrigation layout can be planned to aid drainage and early spring plowing. (Reference 158 and page 70).

Topography and Leveling

For the simplest types of surface irrigation, the land should preferably be smooth, with a gentle slope of between 2 and 8 inches or a little more per 100 feet. Flatter and much steeper slopes can be irrigated by the *Special Methods* described later in this chapter.

Not always in the East will it pay to *level* (that is, to smooth—not to make level) the land as extensively as in arid regions. Since fewer and lighter applications of water are made in the supplemental irrigation of the East than in the complete irrigation of the West, heavy leveling is not so essential, nor will it save so much labor and expense. In many cases the leveling may be perfected by the farmer over the years rather than by a heavy initial investment.

However, initial light leveling will always pay in facilitating the distribution of the water in the fields, and occasionally initial heavy leveling will be advisable. Light leveling may be accomplished inexpensively with the home-made buck scraper and floats of Figs. 9 and 10, or somewhat better with similar manufactured equipment. The float of Fig. 10, or a longer and better one, should be operated over the land every season. It is especially necessary that no low spots be left in the heavier soils, where water may stand in pools and *cook* the crop.

Before the top soil is scraped off the higher land to be deposited in the lower places, in fact before an irrigation layout involving leveling is adopted, the depth of soil should be considered, so that too much top soil will not be removed. It often requires some years and considerable expense to bring such spots back into full production.

Heavy duty earthmoving equipment is commonly used in irrigated regions and will reduce costs on large acreages. The use of a two-way plow, or of special tillage machinery that simply cuts through the soil, will avoid disturbing the carefully leveled surface.

Appendix E gives a detailed treatment of land leveling.

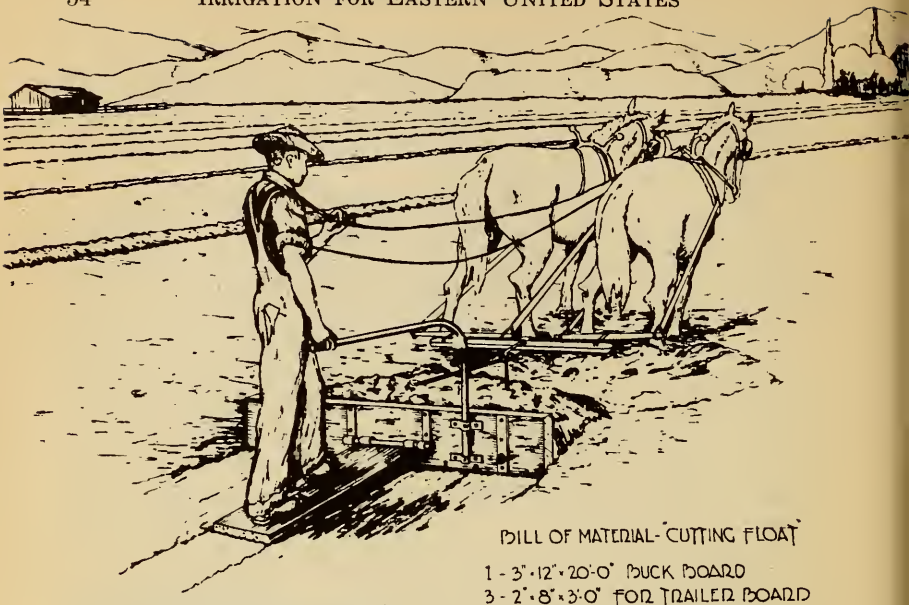
On all except the most uniformly sloping land or under the most favorable conditions, a topographic map, a soil classification, and a soil profile should be provided if best results are to be attained. The general layout shown in Figs. 5 and 40 will be worked out in detail on the topographic map which will usually have contours one foot apart. If contours are not drawn, at least spot elevations and arrows should be shown at important points on the map sufficient to indicate the direction and amount of ground slopes. Maps of this sort can be carried to interested persons at a distance and intelligent layouts made thereon by them. The facts should be recorded on the maps since verbal discussions may be indefinite, misleading, or forgotten.

Studies indicate that farm layouts to fit the topography are usually cheaper and more satisfactory than rectangular layouts unless the slopes are quite uniform and in the direction of one side of the rectangle. See Reference 152.

The map will help toward a wise choice of irrigating methods, field layouts, proper sizes and grades of field ditches and flumes, areas to be left unirrigated, and necessary leveling. Generally, it will prevent difficulties and save money. Such maps have been used for more than a generation on the better managed irrigation projects and are especially necessary in a region unaccustomed to irrigation. A map will cost only a couple of dollars per acre, including expert advice as to the irrigation layout. Examples and specifications for such maps are given on pages 124, 141, and 142 of Reference 1; on pages 12 and 14 of Reference 23; and in Appendix E.

Referring to western irrigation but applying likewise to the East, Reference 28 states,

> In order that water may be applied uniformly and easily, land to be irrigated must be leveled. This leveling removes such humps and hollows as would interfere with the flow of water and improves the slope. The type and amount of leveling required is dependent upon the topography, depth and quality of soil, crops to be raised, method of irrigation to be employed, and flow of water available.
>
> In some areas there has been a trend to reduce the fields to a



BILL OF MATERIAL- BUCK SCRAPER

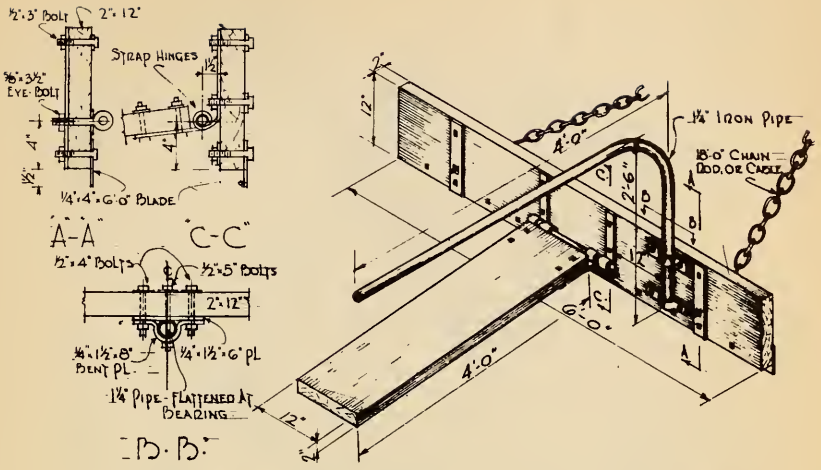
1 - 2" · 12" · 6'-0" = BUCK BOARD
1 - 2" · 12" · 4'-0" - TRAILER BOARD
1 - 1¼" · 6'-6" - IRON PIPE HANDLE
1 - ¼" · 4" · 6'-0" - STRAP IRON CUTTING EDGE
4 - ¼" · 1½" · 12" - STRAP IRON HINGES
2 - ¼" · 2" · 12" - STRAP IRON
2 - ¼" · 1½" · 6" - STRAP IRON --- PIPE CLAMP
2 - ¼" · 1½" · 8" - BENT STRAP IRON " "
1 - ⅝" · 18" - BOLT FOR HINGE
2 - ⅝" · 3½" - EYE-BOLTS
2 - ½" · 5" - CARRIAGE BOLTS
4 - ½" · 4" - " "
22 - ½" · 3" " "
2 - ⅝" WASHERS
28 - ½" "
18'-0" CHAIN-ROD-OR CABLE HITCH.

BILL OF MATERIAL- CUTTING FLOAT

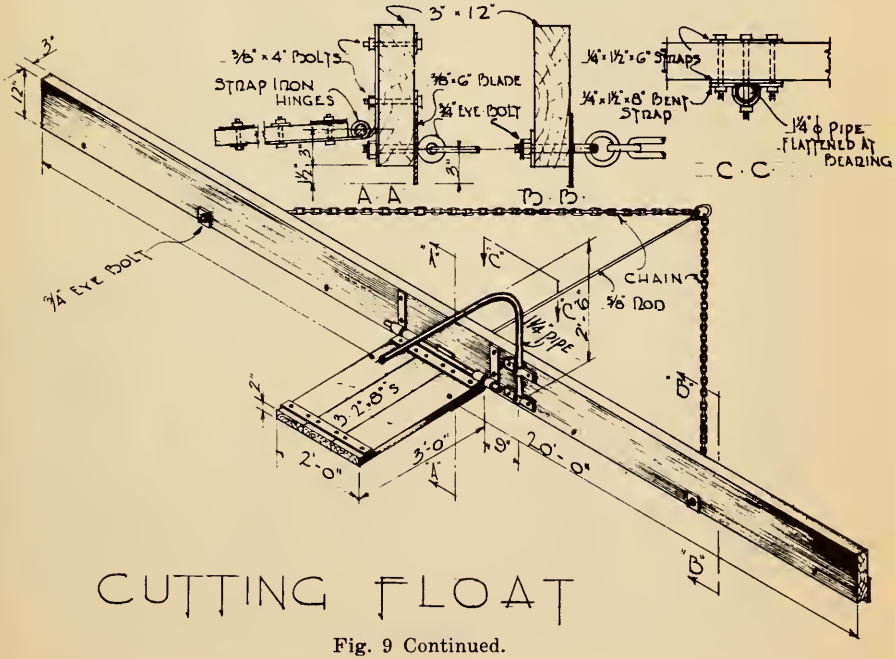
1 - 3" · 12" · 20'-0" BUCK BOARD
3 - 2" · 8" · 3'-0" FOR TRAILER BOARD
1 - 1¼" · 6'-0" - IRON PIPE HANDLE
1 - ⅜" · 6" · 20'-0" STRAP IRON CUTTING EDGE
4 - ¼" · 1½" · 12" - STRAP IRON HINGES
2 - ¼" · 3" · 2'-0" - STRAP IRON CLEATS
3 - ¼" · 3" · 3" - FLAT WASHERS
4 - ¼" · 1½" · 6" - STRAP IRON - PIPE CLAMP
2 - ¼" · 1½" · 8" " " " "
1 - ¾" · 2'-6" BOLT FOR HINGE
3 - ¾" · 5" - EYE BOLTS
2 - ½" · 6" - CARRIAGE BOLTS
4 - ½" · 5" " "
14 - ½" · 3" " "
8 - ½" · 4" " "
22 - ½" WASHERS
1 - ⅝" ϕ · 6'-0" ROD FOR HITCH
2 - 9'-0" CHAINS, CABLE OR RODS FOR HITCH
1 - 4" RING FOR HITCH.

The buck scraper is a convenient and economical implement for moving earth in land leveling operations. It is particularly useful in filling low spots or removing high ones. When drawn by a team of horses it may be used while water is being applied to borders. After the space between border dikes has been leveled with the float, water may be turned in and the leveling process finished as the low and high spots are revealed. The cutting float is used in somewhat the same manner but is drawn with tractor power and is not adapted to wet leveling.

Fig. 9. Buck scraper for land leveling. (Courtesy, U. S. Farm Security Administration.)



BUCK SCRAPER FOR WET AND DRY LEVELING



CUTTING FLOAT

Fig. 9 Continued.

The so-called irrigation "float or "leveler" is used to produce a uniform, smooth land surface, free from minor irregularities over which water may be evenly distributed. In order to function properly the float should have the following structural features:

1. The length should not be less than 18 feet.
2. At least one cross member should be adjustable to allow for variable soil conditions.
3. The use of divided rollers makes turning easier and reduces draft.

Many types of floats are available, both commercial and home-made. The irregularities produced by farming operations make the use of the float desirable each season on all irrigated fields.

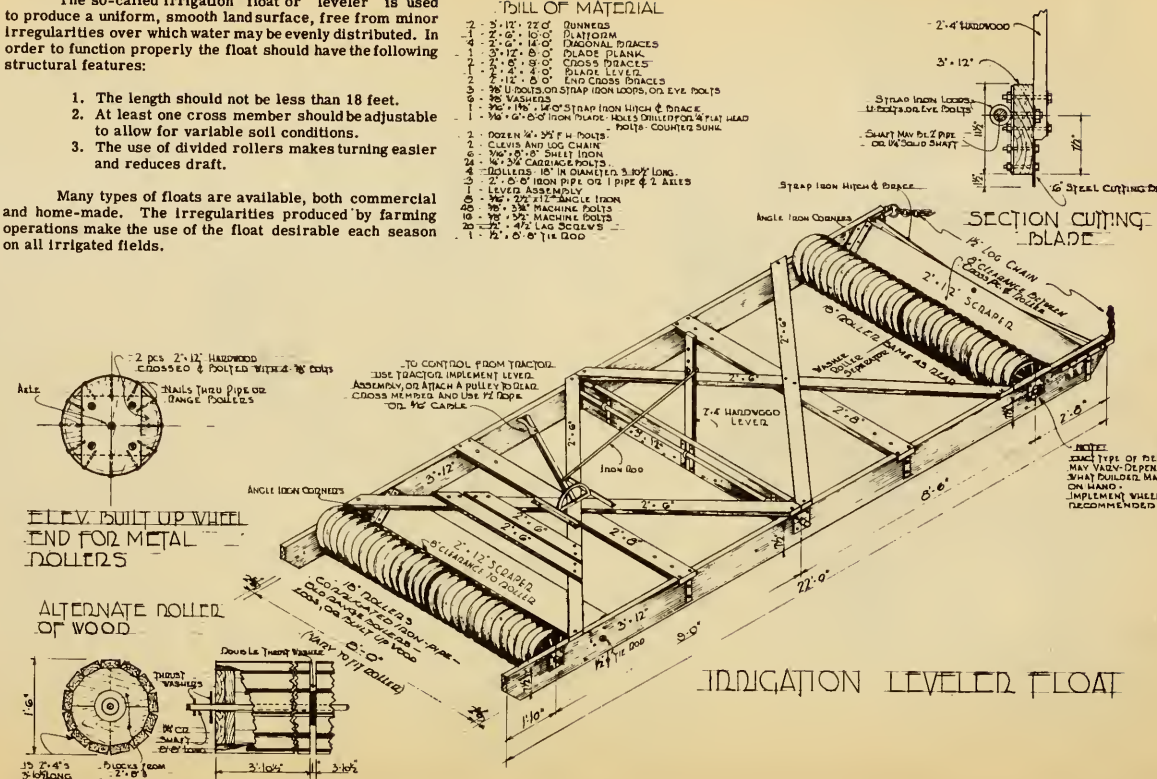

BILL OF MATERIAL
2 - 3"·12"·22'0" RUNNERS
1 - 2"·6"·10'0" PLATFORM
4 - 2"·6"·14'0" DIAGONAL BRACES
1 - 3"·12"·8'0" BLADE PLANK
2 - 2"·6"·8'0" CROSS BRACES
1 - 2"·4"·4'0" BLADE LEVER
2 - 2"·12"·8'0" END CROSS BRACES
3 - 3/8" U-BOLTS ON STRAP IRON LOOPS, ON EYE BOLTS
9 - 3/8" WASHERS
1 - 3/16"·1 1/2"·14'0" STRAP IRON HITCH & BRACE
1 - 1/8"·6"·8'0" IRON BLADE - HOLES DRILLED FOR 1/4" FLAT HEAD BOLTS - COUNTER SUNK
2 - DOZEN 1/4"·3 1/2" F H BOLTS
2 - CLEVIS AND LOG CHAIN
6 - 3/16"·8"·8" SHEET IRON
24 - 1/4"·3 1/4" CARRIAGE BOLTS
4 - ROLLERS 18" IN DIAMETER 3.10 1/2" LONG
3 - 2"·8'0" IRON PIPE OR 1 PIPE & 2 AXLES
1 - LEVER ASSEMBLY
6 - 3/16"·2 1/2"·12" ANGLE IRON
48 - 3/8"·3 1/4" MACHINE BOLTS
16 - 3/8"·5 1/2" MACHINE BOLTS
20 - 1/4"·4 1/2" LAG SCREWS
1 - 1/2"·8'0" TIE ROD
2"·4" HARDWOOD
3"·12"
STRAP IRON LOOPS U-BOLTS ON EYE BOLTS
SHAFT MAY BE 2" PIPE OR 1 1/4" SOLID SHAFT
6" STEEL CUTTING BLADE
STRAP IRON HITCH & BRACE
ANGLE IRON CORNERS
SECTION CUTTING BLADE
1/4" LOG CHAIN
8" CLEARANCE BETWEEN CROSS MEMBER & BOLTS
2'·12" SCRAPER
10" ROLLER SAME AS ABOVE
WASHER ROLLER SPACERS
2"·6"
2"·8"
2"·4" HARDWOOD LEVER
IRON ROD
NOTE: EXACT TYPE OF BEARING MAY VARY-DEPENDING ON WHAT BUILDER MAY HAVE ON HAND. IMPLEMENT WHEEL BEARING RECOMMENDED
2 PCS 2"·12" HARDWOOD CROSSED & BOLTED WITH 4 3/8" BOLTS
AXLE
NAILS THRU PIPE OR RANGE ROLLERS
TO CONTROL FROM TRACTOR USE TRACTOR IMPLEMENT LEVER ASSEMBLY, OR ATTACH A PULLEY TO DRAW CROSS MEMBER AND USE 1/2" ROPE OR 5/16" CABLE
ANGLE IRON CORNERS
2'·12" SCRAPER
8" CLEARANCE BETWEEN ROLLER
10" ROLLERS CONSTRUCTED OF IRON PIPE OR WOOD LOGS, OR BUILT UP WOOD
MAY VARY TO FIT ROLLER
8'·0"
3'·12"
5'·0"
12" TIE ROD
1'·10"
22'·0"
ELEV. BUILT UP WHEEL END FOR METAL ROLLERS
ALTERNATE ROLLER OF WOOD
DOUBLE THRUST WASHER
THRUST WASHERS
1 1/4" CO. SHAFT 6'·0" LONG
15 2"·4"'S 3'·10" LONG
BLOCKS FROM 2"·8"'S
3'·10 1/2"
3'·10 1/2"
NOTE:- ROLLER CAN BE BUILT AS SHOWN OR CAN BE BUILT OF LOG WITH AXLE'S DRIVEN IN ENDS, OR TWO RANGE ROLLERS END TO END FOR EACH ROLLER
IRRIGATION LEVELER FLOAT

Fig. 10. Float for land leveling. (Courtesy, U. S. Farm Security Administration.)

single plane with little resultant improvement in the uniform application of irrigation water. This has added unnecessary expense to the development costs of the land. Much land in the Northwest has sufficient slope to make it unnecessary to grade the entire field. In such cases, smoothing operations accompanied by some *spot leveling* often accomplishes the needed condition for uniform irrigations. Only so much leveling should be done as will assist in the uniform application of irrigation water. Except on land with over-all slopes of much less than 1 foot per 100 feet, the general natural slope will govern. Earth will be moved to avoid level areas or slopes counter to the direction of flow of irrigation water and cross slope on borders.

Benefits from Leveling

The benefits to be derived from leveling form the basis of the farmer's determination of the degree of refinement of the leveling job to be reached. These benefits include less work in applying water, greater yields, and saving of soil and water.

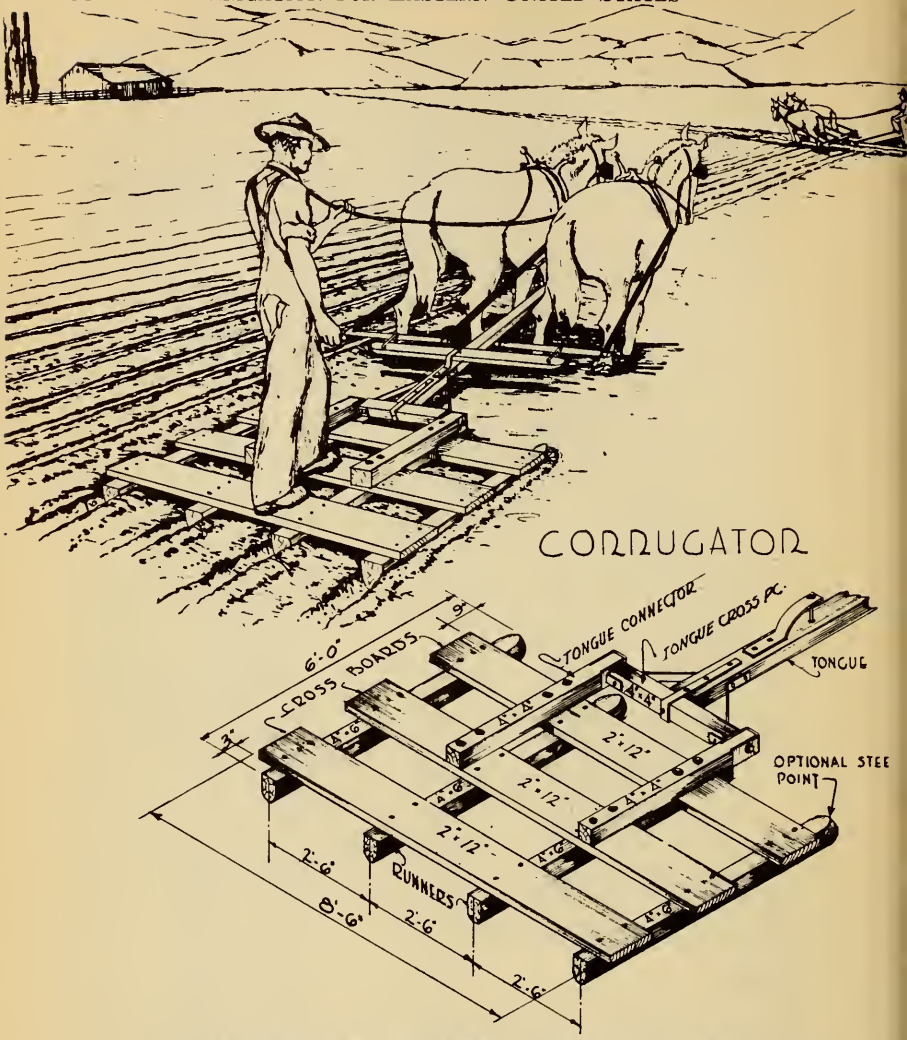
A ground surface free of irregularities will permit an even distribution of water to the land and crop, with a resultant saving in water and labor, and a uniform crop yield. On uneven ground surfaces with high and low spots and with cross slopes, water will move erratically across the field and the irrigator must spend extra time in guiding the flow. In furrow irrigation under these conditions water is likely to break over from one furrow to the next, then to the next, and so on, causing destructive erosion. Extra labor will be required to repair this damage in addition to other harmful effects that may result.

Yields are generally increased, sometimes as much as 50 to 100 per cent, as a result of leveling. This results from avoiding over-irrigated low areas and under-irrigated knolls. A uniform distribution of water will permit an even growth of crops. Where fertilizers are applied to the land with the water, the leveled field will assure a more uniform fertilizer distribution. Water logging and alkali conditions are less prevalent on lands with smooth surfaces.

Conservation of soil and water can best be effected on leveled land. Ponding of water in low pockets or behind ridges results in the use of excessive water, much of which passes below the root zone. Farming uneven ground frequently limits the farmer in his choice of crops and of irrigation methods.

Furrows

The furrow, row, or corrugation method as indicated in Figs. 5, 11, 12, and 13 is well adapted to many Eastern requirements since it is cheap; requires little experience; will serve all row crops; and can be used for most other field crops, although not so satisfactorily. Less leveling of the land is ordinarily necessary. There is some loss of both land and water in this method. With corn and other crops planted in rows, the rows may serve to form wide and deep furrows which are effective.

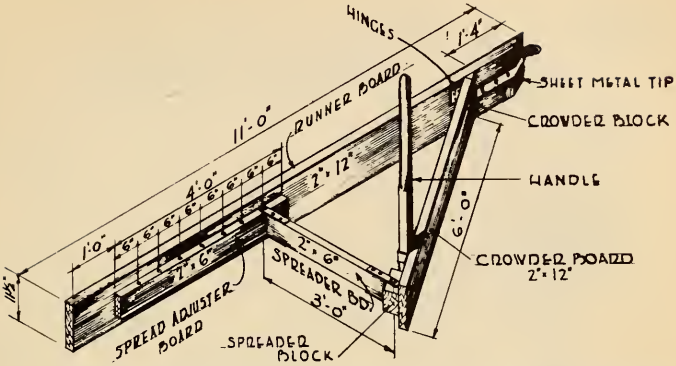


The corrugator is a device used to make small furrows or corrugations for conducting irrigation water over the ground surface. Corrugations are particularly adapted to watering grain or hay crops on irregular fields or for new fields which have not been thoroughly leveled and floated.

The runners are commonly made of 4" x 6" material spaced 30 inches apart. This spacing may vary however, depending on the soil and slope of the land.

Fig. 11. Corrugator for furrowing and ditcher. (Courtesy, U. S. Farm Security Administration.)

ADJUSTABLE CROWDER



The adjustable crowder is essentially a one-way irrigation ditcher. It is adapted to making various width ditches by adjusting the spreader board between the runner and crowder.

Several furrows are first plowed to loosen the dirt. Then the crowder with the crowder board leaning upward and outward crowds the dirt to one side to form the ditch bank. This operation is then repeated on the opposite side to form the other bank.

MATERIAL LISTS

ADJUSTABLE CROWDER

1 PC. 2" × 12" × 11'-0" RUNNER BOARD
1 PC. 2" × 12" × 6'-0" CROWDER BOARD
1 PC. 2" × 6" × 3'-0" SPREADER BOARD
1 PC. 2" × 6" × 4'-0" SPREAD ADJUSTER BOARD
1 PC. 1½" × 2½" × 4'-6" HARDWOOD HANDLE
1 PC. 4" × 6" × 6" - SPREADER BLOCK
1 PC. ⅜" × 2" × 36" STRAP IRON WITH ¾" END - 2½" DIA. HITCH RING.
2 PCS. ⅜" × 2" × 10" HANDLE SUPPORTS.
4 PCS. ⅜" × 1¾" × 8" SPREADER BOARD ENDS.
1 PC. 12" × 12" HEAVY SHEET METAL CUTTING POINT.
3 - ⅜" × 3" BOLTS - HITCH RING TO RUNNER BD.
3 - ¼" × 4" BOLTS - CROWDER BLK. TO RUNNER BD.
16 - ¼" × 2½" BUTTON HEAD BOLTS FOR HINGES
8 - ¼" × 2½" BOLTS FOR HANDLE SUPPORTS.
4 - ⅜" × 7" " " SPREADER BLOCK
2 - ½" × 7" " " " BOARD BEARINGS
4 - ⅜" × 7" " " " " TIPS.
6 - ½" × 5" " " SPREADER ADJ. BD TO RUNNER.
2 PCS. 3" SURFACE HINGES

CORRUGATOR

4 PCS. 4" × 6" × 6'-0" FOR RUNNERS
3 PCS. 2" × 12" × 8'-6" FOR CROSS BOARDS
2 PCS. 4" × 4" × 4'-0" FOR TONGUE CONNECTOR
1 PC. 4" × 4" × 2'-10" FOR TONGUE CROSS PC.
1 PC. OLD WAGON TONGUE
1 PC. ¼" × 2½" × 12" STRAP IRON CLEVIS.
1 PC. ¼" × 1½" × 3'-0" " " TONGUE TO CROSS PC.
2 PCS. ¼" × 2" × 3'-0" " " TONGUE BRACES
2 PCS. ¼" × 4" × 1'-4" " " TONGUE CONNECTOR ENDS
1 - ¾" × 8" BOLT - DOUBLE TREE TO CLEVIS
2 - ⅜" × 6" " - CLEVIS TO TONGUE
7 - ½" × 6" " - TONGUE TO CROSS TIE.
1 - ½" × 8" LAG SCREW - CROSS TIE TO TONGUE
2 - ⅝" × 12" " " CONNECTOR TO CROSS TIE AXLE
8 - ⅜" × 8" BOLTS WITH WASHERS - TONGUE CONNECTORS TO CROSS BOARDS.
24 - 5/16" × 8" CGE. BOLTS - H'DS. IN RUNNERS - CROSS BOARDS TO RUNNERS.

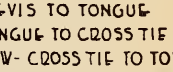
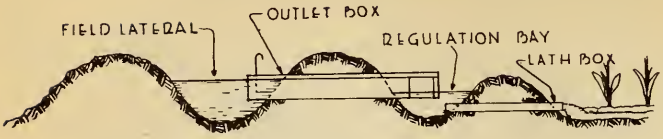


Fig. 11 Continued.



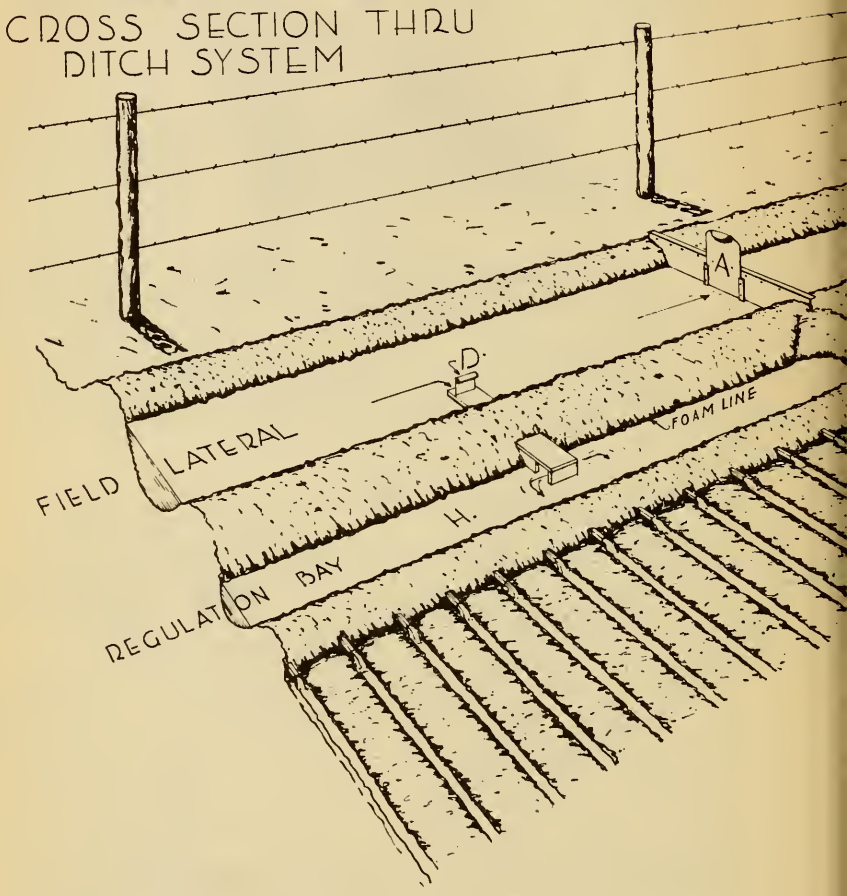
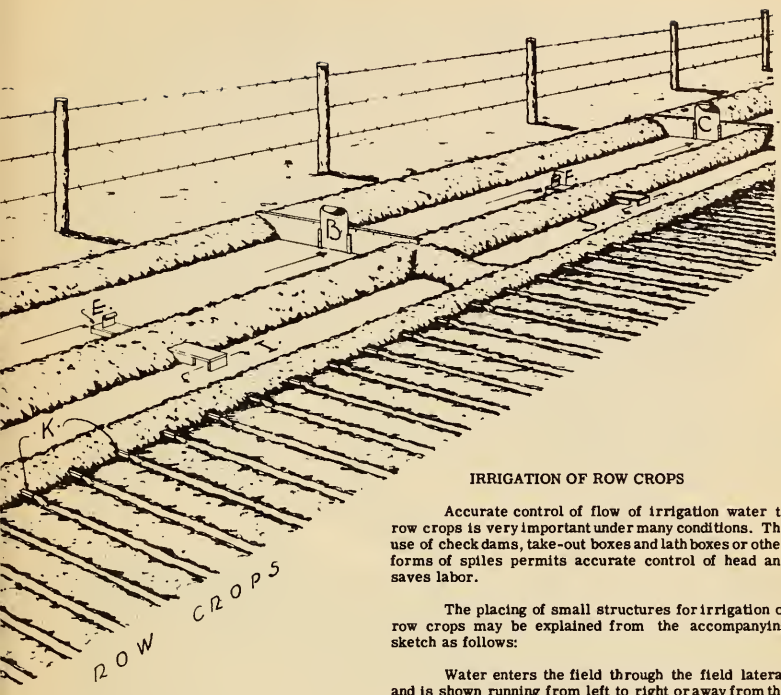


Fig. 12. Furrow irrigation, with lath boxes. (Courtesy, U. S. Farm Security Administration.)



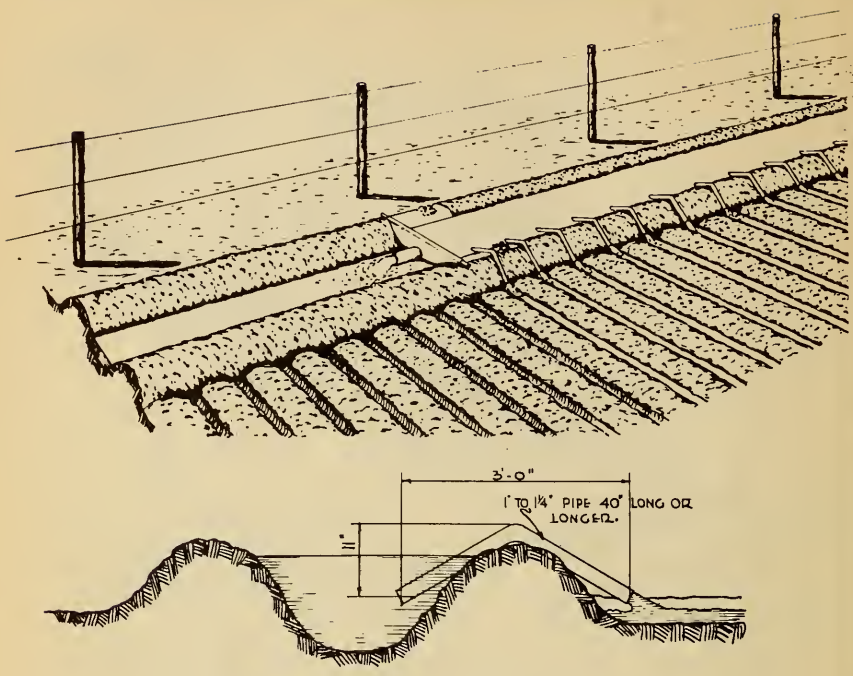
IRRIGATION OF ROW CROPS

Accurate control of flow of irrigation water to row crops is very important under many conditions. The use of check dams, take-out boxes and lath boxes or other forms of spiles permits accurate control of head and saves labor.

The placing of small structures for irrigation of row crops may be explained from the accompanying sketch as follows:

Water enters the field through the field lateral and is shown running from left to right or away from the observer. The secondary ditch or so called "regulation bay" is made either with a plow or some form of ditcher. Small earth dams or checks are placed in "regulation bays" as shown. The spacing depends upon the fall in the field lateral.

1. The metal check dam or canvas dam at "A" is set to raise the level of the water in the field lateral. The by-pass gate in the metal check is opened to allow excess water to pass on down the field lateral.
2. The ditch bank is next cut with a shovel and the take-out box at "D" is placed as shown and well sealed with mud to prevent leakage. The gate in the take-out box is opened to permit water to enter the "regulation bay".
3. Water standing in the "regulation bay" at some given height will form a foam line which permits the setting of the lath boxes or spiles at a given level. A lath box is generally set for each row although where a small head is desired one box may serve two rows. Each lath box should be set as near level as possible and close to the ground in the rows. Each box must be sealed with mud. There is less danger of lath boxes becoming clogged with trash if the head of water in the "regulation bay" is carried above the level of the top of the box.
4. One take-out box will ordinarily serve from 12 to 20 lath boxes. The gate in the take-out box is now opened to allow the desired flow through the lath boxes. The quantity of water flowing through the lath box will depend on the height of water above it. The gate in the check dam is then accurately set to maintain the proper head in the field lateral.
5. After one bay has been set the same process as has been described is repeated in the second bay as shown at "I" and so on until the entire head in the field lateral is used.



SECTION - DITCH & SIPHON

Siphon tubes made of light metal or plastics are sometimes used to distribute water from a field lateral to furrows for irrigation of row crops. Some irrigators prefer this method since it is not necessary to cut the ditch bank to place the tubes and the use of a "Regulation Bay" or secondary ditch is not required. It has the disadvantage of being difficult to regulate and if flow in the lateral is interrupted the siphon action in all tubes must be started again.

The siphon action is started as follows:

1. The tube is filled with water by submerging it in the canal.
2. The hand is placed over one end and the tube set in position as shown in the drawings.
3. When the hand is removed flow will start and may be adjusted by raising or lowering the discharge end.
4. The intake end of the tube should be placed far enough under water to eliminate clogging by floating trash.

Fig. 13. Furrow irrigation, with syphons. (Courtesy, U. S. Farm Security Administration.)

Ames Gated Surface Pipe. Controlled furrow irrigating started this bean crop in California.

Ames Surface Pipe, not gated, for transporting water without loss—no ditch tending. Corn in Nebraska.

Fig. 14. Surface pipe. (Courtesy, W. R. Ames Company.)

Supply ditches, gated surface pipes, or flumes (Figs. 12, 13, 14, 43, and 44) are located either along the upper border of the field, along contours, or along the ridges to regulate the flow in the furrows. In the latter case, the water runs both ways in the furrows from the ridge ditch.

The length of the runs of water should be of the order of those shown in Table II.

TABLE II

LENGTHS OF RUN FOR FURROWS AND CORRUGATIONS ON VARIOUS SLOPES AND SOIL TEXTURES*

Slope (per cent)**	Length of furrows or corrugations—soil texture			
	Loamy Sand and Coarse Sandy Loams	Sandy Loams	Silt Loams	Clay Loams
0–2	250–400	300–660	660–1320	880–1320
2–5	200–300	200–300	300–660	400–880
5–8	150–200	150–250	200–300	250–400
8–15	100–150	100–200	100–200	200–300

With the longer runs the upper portion is over-watered, the lower end cannot be observed readily, and difficulty is encountered on flat slopes or porous soil in getting the water to the lower end of the furrows. The amount of water admitted to each furrow will vary with the soil, the slope, and the length of the furrow. The holes in flumes and gated surface pipe are 1 inch in diameter and regulated by sliding gates.

It is common practice to double the flow of water in the furrow until it quickly reaches the lower end, then to reduce to the normal flow. An attempt is made to use only enough water to keep the lower end wet, without waste. From 5 to 15 gallons per minute is normally used and the larger flows will erode usual soils badly on slopes of 24 inches per 100 feet or more. On steep slopes as little as 1 gallon per minute may suffice. Furrows generally should run squarely down the slope which should be ideally between 2 and 8 inches or a little more per 100 feet, although much steeper slopes can be used. If the furrows angle across the slope (less than 30 degrees away from the direction of slope) then the furrows must be made deeper to prevent the water from breaking across the furrows.

Furrows following the contour of the ground, but with slopes

*U. S. Bureau of Reclamation, Reference 28.
**The slope, or grade, per cent is the vertical drop in feet per 100 feet horizontally.

of about 6 inches per 100 feet, have been used successfully on certain soils, topography, and row crops (Reference 160.)

Corrugations, Fig. 11, aid in distributing water for pastures or hay crops on uneven ground but interfere to some extent with harvesting a crop.

Border Checks

Border checks, such as those shown in Figs. 5, 15, and 40 extend down the natural slope not exceeding 2 or 3 feet per 100 feet, and preferably less, with low embankments to guide the water. They are preferred for alfalfa, clover, and similar crops. The water spreads evenly over the upper 20 or 30 feet of these checks, which must be made entirely level in both directions, and flows to the lower end.

Each border check must be made level transversely throughout its length. More land leveling is required than for furrow irrigation; there is the same loss of land and water; and water should percolate uniformly throughout the length of this run. Checks should conform to Table III. A minimum flow of water of 1½ cubic feet per second is desirable, and more is usually preferable.

In starting the crops on soil that bakes or crusts and on steep slopes, corrugation may be used and never reopened. Seed may be drilled with the slope to aid flow or across the slope to retard it. Before the crop is up, extreme care must be taken to avoid erosion on the steeper slopes.

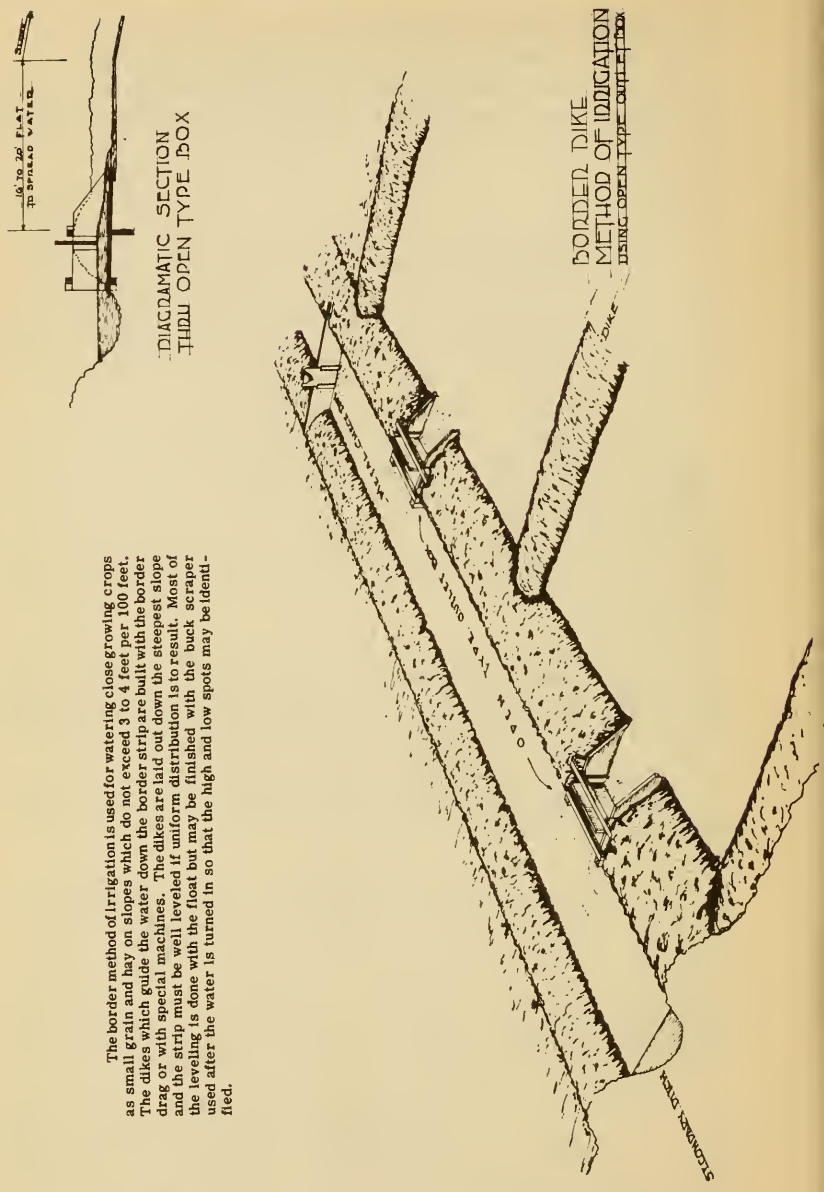
Border checks facilitate crop rotation, first for pasture, then for furrows and row crops, or vice versa.

TABLE III

WIDTH AND LENGTH OF BORDERS FOR VARIOUS SOILS AND SIZES OF IRRIGATION STREAMS*

Irrigation stream delivered to each border (cubic feet per second)	Soil textures					
	Sandy		Silt Loam		Clay	
	Width	Length	Width	Length	Width	Length
	Feet	Feet	Feet	Feet	Feet	Feet
1	20	200–300	25	330–550	30	550–770
1–2	30	330–400	35	550–770	40	660–880
2–4	35	440–550	40	550–770	50	660–1000
4–6	40	550–660	50	660–880	60	880–1320
6–8	66	660–770	66	880–1320	66	1320–1500

*U. S. Bureau of Reclamation, Reference 28.



The border method of irrigation is used for watering close growing crops as small grain and hay on slopes which do not exceed 3 to 4 feet per 100 feet. The dikes which guide the water down the border strip are built with the border drag or with special machines. The dikes are laid out down the steepest slope and the strip must be well leveled if uniform distribution is to result. Most of the leveling is done with the float but may be finished with the buck scraper used after the water is turned in so that the high and low spots may be identified.

Fig. 15. Border checks. (Courtesy, U. S. Farm Security Administration.)

Contour Checks or Contour Borders

These are formed on flat slopes (a few tenths of a foot per 100 feet) by level low embankments following the contour of the ground, but with a slope of less than 0.1 foot per 100 feet along the contour. They are leveled between borders and allow the water to stand in nearly level ponded areas and to seep into the ground. They are seldom used except for rice. Rice is one of the few crops where ponding of water is essential. Water standing on the heavier soils may harm other crops.

Level Rectangular Checks

This type of checks, sometimes called basins, Figs. 5 and 40, will seldom be used because excessive leveling of the heavy soil is required unless the original land was very flat.

Wild Flooding

Here the water is distributed from ditches along contours, at right angles to contours, along ridges, or along high ground. Although inefficient, it is occasionally used for other than row crops where water is cheap and crop values are low. Little leveling is necessary.

Because of the lack of guide furrows or embankments for the water used in wild flooding, the supply ditches are spaced from 200 feet apart on slopes of from 5 to 8 feet per 100 feet up to 400 feet or more apart on heavy soils with slopes of 1 foot per 100 feet or less.

Miscellany

Contour ditches, shown in Figs. 5, 16, and 40, may be combined with erosion-control terraces, as mentioned in the third section following entitled *Disposal of Excess Water.*

It is difficult to distribute the water uniformly from the border ditches in the lower right corner of Fig. 5.

Flooding cannot be used successfully on some soils because of the resulting puddling and crust formation. Cultivation immediately after irrigation, when this is possible, will relieve this difficulty.

It should be kept in mind that over the years many different types of crops may be raised on the same field. A type of land leveling which will effectively serve row crops, pasture crops, and other crops is advisable. The most adaptable leveling will permit both border checking and furrowing with the furrows running in the direction of the borders.

The use of contour ditch irrigation is favored in many sections for watering small grain, pasture and hay on irregular slopes or those in excess of 2 or 3 per cent. The success of the system depends upon the care with which the contour laterals are placed. It is customary to build the ditch across the slope with no grade or with less than 1/10 of one foot per 100 feet. In some cases water is diverted to the land directly from the contour ditch. A better method consists of plowing a furrow on the lower side of the contour ditch, throwing the furrow slice uphill. The flow is diverted from the contour ditch to the furrow by means of take-out boxes. Water spilling over the lip of the furrow passes down over the slope in a uniform sheet if the system has been carefully layed out and constructed.

Fig. 16. Contour ditch irrigation. (Courtesy, U. S. Farm Security Administration.)

Sub-Irrigation

This method supplies the water laterally and upward from ditches or drain tile below the surface of the ground, and has been used only in a few localities (References 1, 7, and 18).

Special Methods for Steep and Flat Slopes

It must be expected that surface irrigation will be somewhat more difficult and expensive on the steeper and flatter slopes.

On slopes exceeding 8 inches or a little more per 100 feet, up to several feet per 100 feet, very skillful irrigation is required to prevent erosion, especially before the crop is up, and to slow the flow of water so that it will have time to soak into the ground. Small checks or areas and small quantities of water are used for flooding. Where furrows run down the slope, only trickles of water are used in short furrows. If the deep furrows approximately follow the contour across the slope, as in some orchard irrigation, the usual 5 to 15 gallons per minute may be used in each furrow. Contour terraces are sometimes used for the distribution of irrigation water.

Water does not flow readily over land sloping less than 2 inches per 100 feet. Deeper, smoother, and shorter furrows or rows; contour checks; or level rectangular checks will serve here to apply the water.

Of course, porous hose and sprinklers can be used on both flat and steep slopes.

Reference 28 and Appendixes E and F give detailed information for establishing surface systems but usually it is better to leave this to experienced irrigators.

Costs

Original or installation costs for surface systems, including pumping units and simple wells or other simple water sources, may run from $60 to $100 per acre, occasionally outside of these limits. The costs are low on large acreages and high on small acreages. Much of the cost is for labor and the use of farm equipment and does not involve a large cash outlay.

Disposal of Excess Irrigation Water

Where surface systems are used, wastage of irrigation water will cost money and labor, and may cause poor drainage, erosion, or other damage. It is the usual, but not the best, practice to allow a head of water to run through rows or borders and be

wasted at the lower end of a field by running it into roadside ditches or elsewhere.

Care in the handling of irrigation water can result in a saving of both water and labor, and will prevent the common mistake of over-irrigating parts of the crop. A set may be made at "A" in Fig. 17 and rows irrigated from lateral "D" down the slope toward lateral "E". The waste water is collected above lateral "E" and cut into it at "X". This excess water is used to

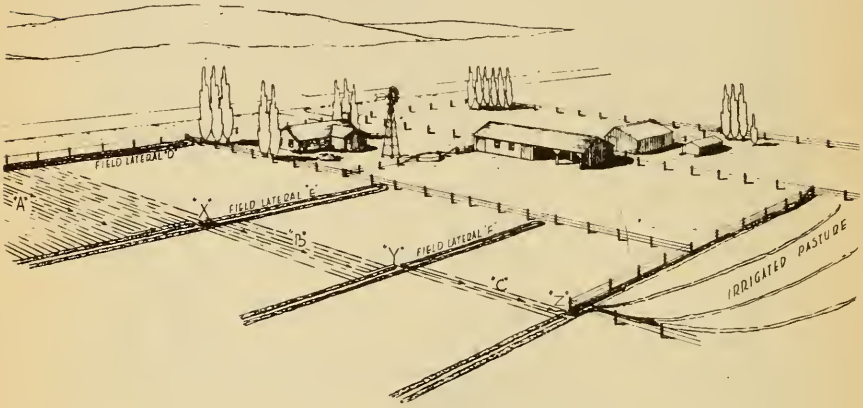


Fig. 17. Disposal of excess water. (Courtesy, U. S. Farm Security Administration.)

irrigate additional rows at "B" and the excess water used at "C". The same practice may be applied in the case of borders or corrugations.

By careful arrangement of fields and pastures the waste water from one portion of a farm may be economically applied elsewhere.

Combining Soil Conservation and Drainage With Surface Irrigation

In many cases of supplemental irrigation in humid regions, drainage of excessive rainfall is a major or minor problem.

Where these can be combined on suitable topography, erosion and leaching of plant nutrients is minimized while farm operations and early plowing are facilitated.

For many layouts like Fig. 17 where the land slopes from ½ foot to several feet per 100 feet, the field laterals or ditches are often below the ground level and the rainfall runoff may be cut into them, often just below a *drop* or *check* in the lateral.

Where the land slopes less than ½ foot per 100 feet, usually in river bottoms or flood plains, the methods described in Reference 158 may be used.

In a third case some ingenious modification of the foregoing two methods may be possible. The additional cost per acre for drainage is negligible for the first case above, and perhaps $30 to $40 per acre additional for the second and third cases. Occasionally erosion control terraces also may be used for irrigating.

CHAPTER VI

IRRIGATION BY SPRINKLING

For those not skilled in irrigation, sprinkling offers the surest method of applying water; it may be used on rough topography without leveling and without experienced irrigators; and where pumping would be required in any event for surface methods, it may well be the best method. Sprinkling is widely and increasingly used as is indicated in Appendix D and by many publications, among the more recent of which are References 18, 28, and 201 to 220 inclusive. Aluminum pipe manufacturers shipped 1¼ million pounds of sprinkler system pipe in 1946; an estimated 30 million pounds in 1953; 24 times as much.

The labor of applying water by sprinkling or surface methods is about the same but the latter requires more experience and skill and such labor will be more expensive in the East until skill is developed.

Design

The rotary sprinkler and overhead spray systems, as shown in Figs. 8, 18 to 22 inclusive, 26, 28 and as described in Appendix D and References 18, 28, and 201 to 220 inclusive, are used where pressure is available, usually from pumps. They may consist, at least in part, of permanently placed pipe, but many of the pipes are laid temporarily on or above the surface and can be moved from place to place, thus minimizing the original cost.

Figure 8 shows a typical simple sprinkling system in which the 3-inch portable laterals are moved to successive outlets on the permanent underground main. Other systems are shown on Figs. 26 and 28. Many alternate layouts can be used, and each irrigation development requires its own individual solution.

Few irrigators would install sprinklers on flatter topography for corn or such tall crops because of handling difficulties, and because the rows are well adapted to furrow irrigation. However, sprinklers can be used and may be better when another crop is grown later on the same land.

Sprinkling must be designed and operated to meet specific local conditions of labor, soil, crops, topography, and wind. Even

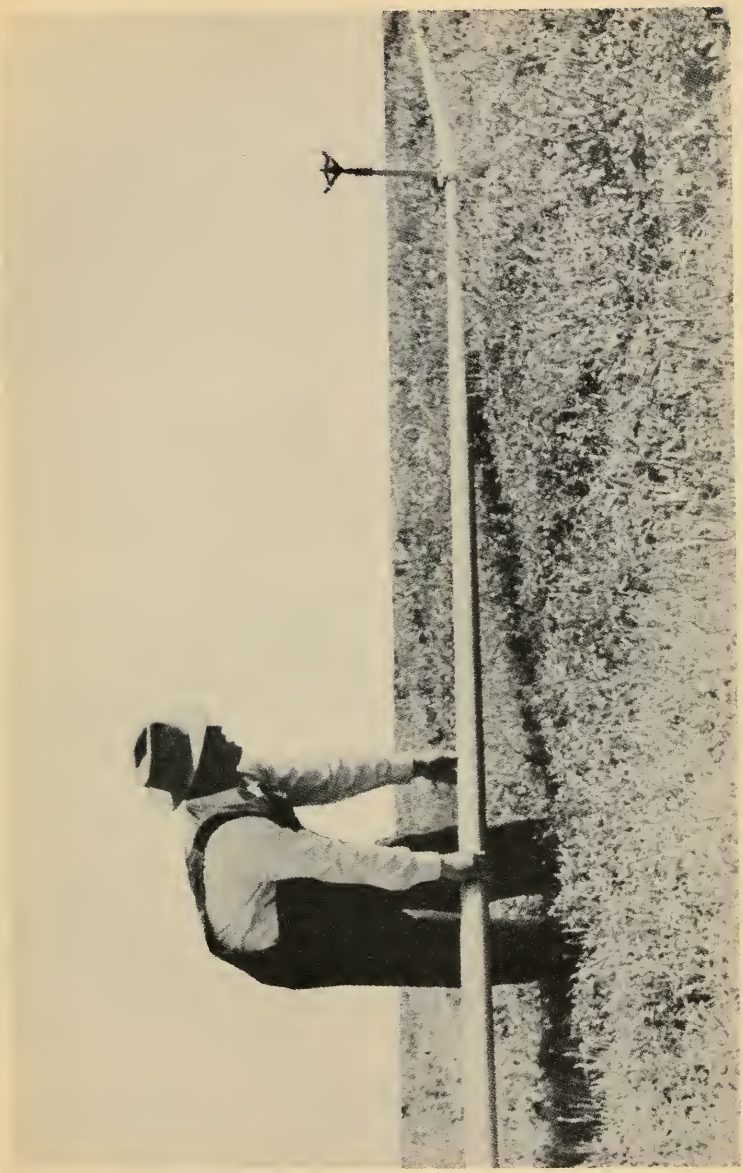


Fig. 18. Rapid coupling for portable pipe. (Courtesy, Aluminum Company of America.)

Fig. 19a. Portable pipe and rotary sprinklers. (Courtesy, Skinner Irrigation Company.)

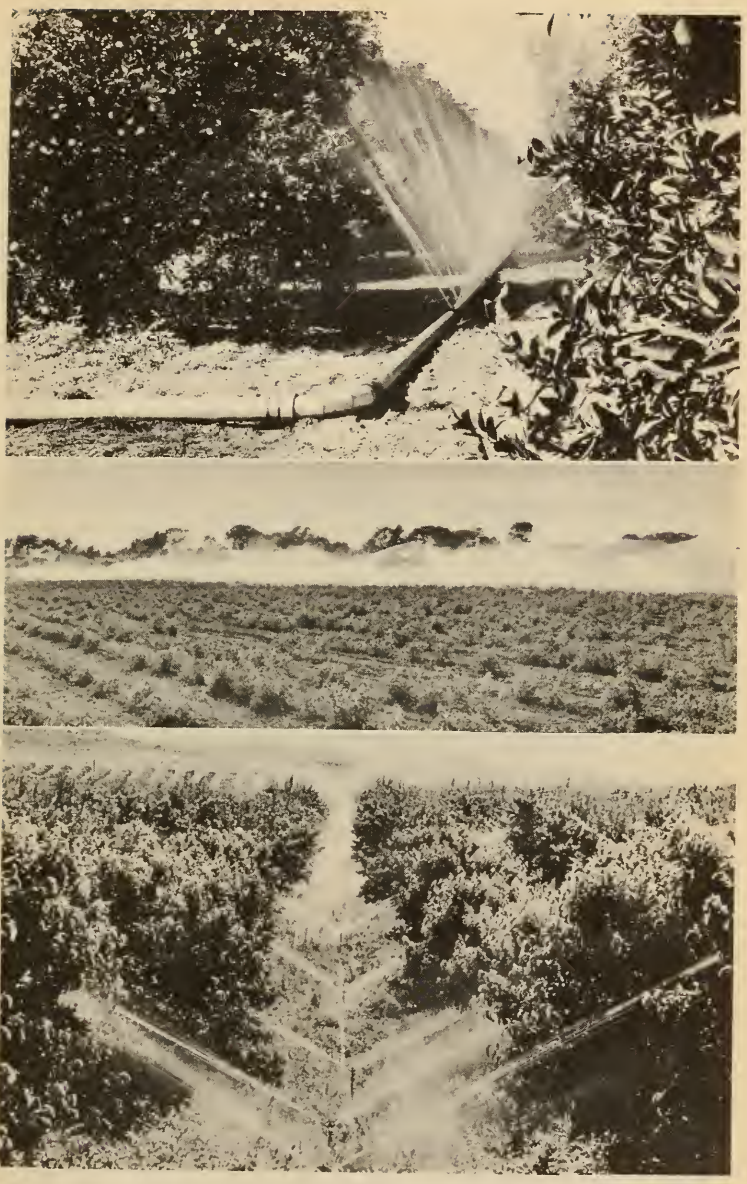


Fig. 19b. Perforated pipe and rotary sprinklers. (Courtesy, Aluminum Company of America.)

Fig. 20. Sprinkler irrigation. (Courtesy, California Culvert Co.)

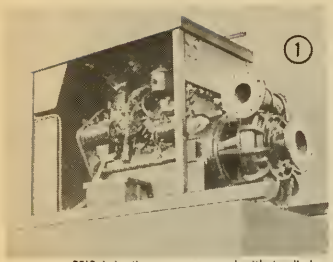
Fig. 21. Sprinkler irrigation for alfalfa and clover. (Courtesy, California Culvert Co.)

the impact and size of the drops of water is important in securing infiltration and preventing erosion and crusting of the soil. By careful design the infiltration rate can be established within 1/20 of an inch per hour, far closer than is necessary. However, the choice of a proper infiltration rate is of greatest importance. Irrigation must be very carefully planned for land with a low infiltration rate.

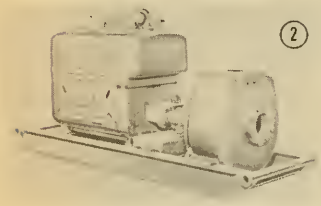
The sprinkling system can be designed so as to use labor when it is available or can be secured, often a difficulty with surface systems where the irrigator must be highly skilled and therefore generally used fulltime on irrigation.

The dealers in sprinkler equipment are pleased to furnish designs and estimates, and they should be consulted. Appendix

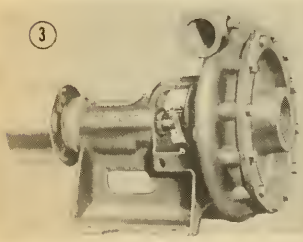
What's New in IRRIGATION



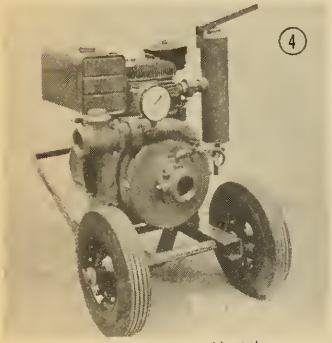
PFIR irrigation pump powered with 6-cylinder Industrial Engine is made by Hale Fire Pump Company, Conshohocken, Pa.



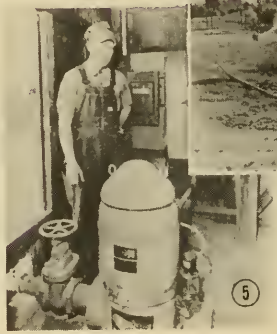
Model SP6x6FG high-pressure self-priming centrifugal pump is made by Barnes Manufacturing Co., Mansfield, Ohio.



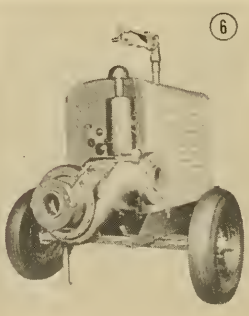
Belt-driven centrifugal pump made by Goulds Pumps, Inc., Seneca Falls, N. Y., gives flexibility for varying conditions.



Model 2C8S irrigation pump with rated capacity of 116 g.p.m. is manufactured by Marlow Pumps of Ridgewood, N. J.

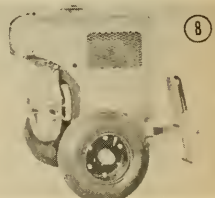


Vertical turbine pump with rated capacity of 350 g.p.m. is manufactured by the Worthington Corporation, Harrison, N. J.

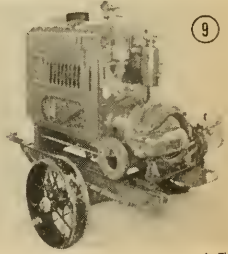


Model 5 WHI irrigation pump with rated capacity of 950 g.p.m. at 90 lbs., made by Carver Pump Co., of Muscatine, Iowa.

Rainbow Manufacturing & Sales Co., Chattanooga, Tenn. Volume gun covers up to 3 and one-half acres at one setting.



Side suction centrifugal pump of The Deming Company, Salem, Ohio, is close-coupled to Wisconsin air-cooled engine.



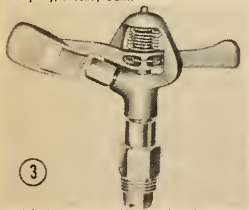
Model 5ST-DIX6D two-stage pump of The Gorman-Rupp Co., Mansfield, Ohio, is powered by a Hercules diesel engine.

Fig. 22. Sprinkler irrigation. (Courtesy, American Fruit Grower, June, 1953.)

EQUIPMENT ?

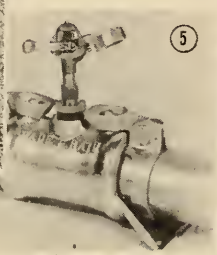
Left—Dolly assembly for Wheel-Trec sprinkler irrigation system, made by Farmland Irrigation Company of Fresno, Calif.

A Wheel-Move lateral line shown sprinkling in alfalfa, is manufactured by Farmland Irrigation Company, Fresno, Calif.



Model No. 20A sprinkler head with capacity of 1.1 to 9.4 g.p.m., is manufactured by National Rainbird Sales, Azuse, Calif.

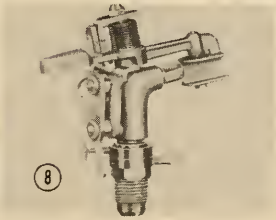
Buckner two-nozzle dual action sprinkler is menufactured by the Buckner Manufacturing Company, Inc., Fresno 8, Calif.



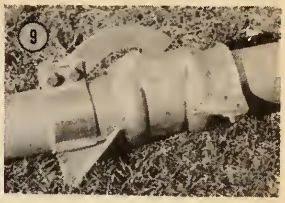
Standard Self-locking Wade 'Rain coupler, made by R. M. Wade & Co., Portland 9, Ore., is adaptable to all types of pipe.

O. K. Champion aluminum irrigation pipe coupling assembly is manufactured by Champion Corporation, Hammond, Ind.

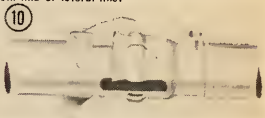
Racebilt "Linklok" coupler, which is manufactured by Race end Race, Inc., Winter Haven, Fla., insures tight fitting.



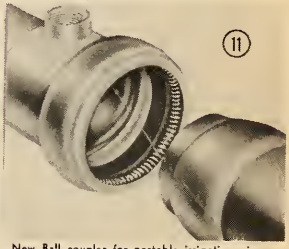
Low-angle part circle sprinkler is made by The Skinner Irrigation Company, Troy, Ohio, rotates from 20° to 340°.



Coupler No. CLP-303, made by Rainway Irrigation Co., Spokane, Wash., can be used for main line or lateral line.



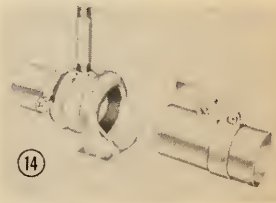
Steelume "Press-In" coupler, distributed by Western Irrigation & Equipment Co., Eugene, Ore., assures positive fit.



New Ball coupler for portable irrigation pipe connections is made by W. R. Ames Company, San Francisco 7, Calif.

McDowell coupling with automatic gasket-coil, pressure-lock design, made by McDowell Mfg. Co., Pittsburgh 9, Pa.

Rain Control coupler, equipped with positive lock, is made by Hardie Manufacturing Co., Los Angeles 58, Calif.



Shur-Rane self-locking latch, made by Food Machinery and Chemical Corp., San Jose, Calif., speeds up coupling of lines.

Fig. 22 (Continued).

D and References 18, 28, and 201 to 220 inclusive give some design data, but the design should be left to experienced irrigation engineers.

Advantages Versus Disadvantages

When carefully designed and installed it is unnecessary to have irrigation experience to operate sprinkling, a considerable advantage over surface irrigation. Sprinkling has been improved recently, has been extended to cover large areas and many kinds of crops, and has become increasingly popular, especially in the East and for new installations. It provides excellent control of water; costly leveling on rough ground is unnecessary; flumes and ditches are eliminated; both water and land are saved; excellent incorporation of water and fertilizer may be obtained; and deep percolation is minimized for thin or porous soils.

On the other hand, the first cash cost of sprinkling is high; somewhat larger pumping costs are required to maintain adequate pressure; and sprinkling does not operate to best advantage in windy climates.

A list of the advantages of sprinkling as claimed by practical farmers and agricultural experts in the West is quoted directly from Reference 18 as follows:

1. Requires less water to accomplish the desired penetration than other forms of irrigation.
2. The water enters the soil in the same way as natural rainfall.
3. Soil does not form a heavy crust.
4. No leveling and grading expense necessary. Portable sprinkler irrigation operates effectively on sloping or rolling land.
5. No loss of fertility due to moving top soil in grading and leveling.
6. No posts or pipe left in the field after irrigating when portable systems are used.
7. The absence of ditches and laterals makes possible the planting of the entire acreage, facilitates cultivation, and does away with obnoxious ditch weeds.
8. This type of irrigation brings up weeds when row crops are small. Weeding can be accomplished early and weed trouble eliminated.
9. Portable sprinkler irrigation, like natural rainfall, washes dirt and dust from leaves and stems and keeps pores open.
10. Sprinkling aids in pest control.
11. Portable sprinkler irrigation prevents alkali from coming to the surface. Sub-irrigation brings it to the surface.
12. With this system, plowing and planting can be carried on independently of weather conditions. The soil can be put in condition at any time for working and for the germination of seed.
13. Portable sprinkler irrigation is especially useful in securing com-

plete germination to insure a good stand. The soil at the surface can be kept in the most desirable condition to allow the plants to come up and thrive.

14. Fertilizer solutions can be introduced into the water. This is a successful and labor saving method.
15. Water can be applied at a very slow rate thus protecting the soil against surface erosion. This is very important where crops are planted on slopes, where in the past the top soil has washed away.

Advantages and disadvantages, mainly the former, also were recently well summarized in Reference 218.

Get Sound Advice

While it may seem that there is nothing very complicated about planning and installing a portable sprinkler irrigation system, the only safe procedure is to *get sound advice* before proceeding to irrigate by this method. Teachers of agriculture can lay the educational background. Information can be obtained from irrigation engineers, county agricultural agents, soil conservationists, state agricultural colleges, or from among the more competent and reliable suppliers of sprinkler equipment. The planning of an efficient portable sprinkler system is an engineering job that can be done best by a competent engineer experienced in this kind of work. Possible savings from a well planned system will more than pay the costs of this service. It would be impossible to write a book which would cover, completely, correct irrigation practice for every section of the country. Too much depends upon local conditions. For this reason one should get the answers that apply to the individual's particular requirements from those best qualified to study needs and offer sound advice for an efficient system.

Fortunately, skilled sprinkling advisers are usually available throughout the East whereas experienced advisers for surface methods are rare.

Costs

Recent installation costs for satisfactory sprinkler systems, including pumping units and simple wells or other simple water sources, of from $100 to $125 per acre are common throughout the country although lower and higher costs are encountered. The costs per acre are lower for larger acreages and higher for smaller acreages. Agents for the manufacturers and distributors will gladly furnish information, designs, and bids on suitable systems for a particular farm. It is wise to have an irrigation engineer approve their proposals.

Sprinkling in the West

The following quotation from Reference 28 is a discussion of sprinkling in the West that is largely applicable in the East.

Good land-preparation, water-control methods and structures will enable efficient use of water and labor on land well suited to surface methods. On less suitable land, sprinkling may be the best solution. Also, the sprinkler method of irrigation gives promise of making it possible to irrigate land which is otherwise non-irrigable.

Before a final decision is reached regarding the use of sprinkler irrigation, careful consideration should be given to many important factors. A few of the most important items, a consideration of which will aid the settler choose the method which best meets his need, are discussed herein.

The greatest advantage of sprinkler irrigation over surface methods is its adaptability to use under conditions where surface irrigation methods are inefficient. Examples are land that cannot be economically prepared for surface methods, excessive slopes, irregular topography, erosive soil, excessively permeable or impermeable soil, land with a shallow soil over gravel or sand, or combinations of these factors. These lands can be served best by sprinkler irrigation, but the returns per acre must be sufficient to bear the high installation and operating costs. Sprinkler systems are also advantageous where the irrigation stream is too small for effective use by surface methods and where moving of sprinkler lines once or twice a day fits into the farm work schedule.

Floating is generally the only leveling operation required for sprinkler irrigation. Consequently, uneven soil fertility caused by the removal of soil from high areas during leveling operations is avoided. The cost of preparing the land for irrigation is generally much less than for the conventional surface methods of irrigation. The reduced leveling operations and the ability to apply water to all areas of a field makes it possible to bring new land into production more rapidly with sprinkler irrigation. Under some conditions it is easier to establish stands of grass, small seeded legumes, and row crops such as sugar beets and onions with sprinkler irrigation.

An advantage of sprinkler irrigation is the saving in water that this method makes possible. Water can be almost completely controlled so that it can be applied in the locations and amounts that are required. Thus, losses due to unequal distribution are reduced.

Against these advantages must be weighed the fact that the purchase of a sprinkler irrigation system calls for a large initial investment. Depreciation of this equipment constitutes a large item of expense. The annual power cost of operating the system is also relatively high. The labor requirement for moving pipe under present conditions will generally exceed the labor requirement for surface irrigation* unless the latter is being employed on porous, steep, or rough terrain.

*Author's Note—This statement applies in the West for skilled surface irrigators; not in the East where they are seldom obtainable.

Because of its high cost, the sprinkler method was formerly limited to use on high-value nursery, fruit, and truck crops in the arid sections and for supplemental irrigation in the more humid areas of the United States, where light applications are desired. More recently, however sprinklers are being used on practically all crops.

Annual Cost Comparison

It may also be well to acquaint the tentative purchaser of a sprinkler irrigation system with a method of comparing the two methods of irrigation on an annual cost basis. A cost comparison may be made by analyzing the following costs and applying them to the areas being considered.

Sprinkler Method*

1. Interest on total investment on sprinkler equipment.
2. Depreciation on sprinkler equipment: Portable equipment, possible life expectancy, 15 years; dipped steel pipe, possible life expectancy, 15 years; dipped wrapped steel pipe, possible life expectancy, 30 years.
3. Labor requirements: The moving of pipe on the portable lateral-type of system usually requires from ¾ to 1 hour per acre per application; this figure includes the return of the lateral to the head of the field after an application has been completed, sump cleaning, and valve regulation. As yet, little information is available of the labor requirements of wheel-move laterals.
4. Power costs: Electric power at a rate of 1 cent per kilowatt hour will cost approximately $1.50 per acre-foot of water pumped from a farm turnout.
5. Maintenance: Maintenance on sprinkler systems usually amounts to 20 percent of the labor cost used in moving lateral pipes. For example, if the equivalent of $12 per acre per season is required for labor in moving pipe, an additional $2.40 per acre would be expended for upkeep and repairs.

Surface Method*

1. Interest on investment in land leveling and distribution system.
2. No depreciation on land leveling. Depreciation on distribution system: Wood structures, possible life expectancy, 5-10 years; pressure treated wood, possible life expectancy, 20-30 years; concrete structures, possible life expectancy, 30 years.
3. Labor requirements: Surface irrigated farms, which permit field layouts having runs of 440 feet or more, usually require from ⅛ to ¾ hour per acre per application. There appears to be justification when considered on a cost basis for sprinkler irrigation when labor requirements exceed 1½ hours per acre per application.
4. Power costs: No power required for pumping on farm units receiving water from Bureau of Reclamation canals for surface irrigation.
5. Maintenance: Maintenance on surface system consists of floating, clearing corrugations, ditches, and distribution systems repair and upkeep. This will approximate between 4 and 5 hours per acre per season.

*Author's Note—These costs apply to U. S. Bureau of Reclamation Projects in the West and are not entirely applicable in the East. See an eastern comparison in the preceeding chapter.

Standards for Design, Installation and Performance of Sprinkler Irrigation Equipment*

DEFINITIONS

Design Area

The specific land area which the supplier or designer and the purchaser mutually understand will be irrigated by the sprinkler system.

Sprinkler Irrigation System

Includes all equipment required to apply water to the design area, from the source of water supplying the system to the revolving sprinklers, nozzles, or perforated pipe.

If water is already available to the design area, the system includes only the equipment required to develop the necessary pressure and apply the water to the area.

If both water and pressure are available, as in the case of an existing pressure line, the system includes only the equipment required to take water under pressure from the supply line and apply it to the design area.

Sprinkler Lateral

A line of portable pipe or tubing with sprinklers, nozzles, or perforations along the line. A lateral may be one of several operated from a common main supply line, or may be a single unit supplied directly from the water source.

Application Rate

The equivalent rainfall rate, expressed in inches of water depth per hour, (acre-inches per acre per hour). For systems with rotating sprinklers the rate is computed on the basis of the spacing of lateral settings, the spacing of the sprinklers along the lateral, and the average discharge of the sprinklers. For perforated pipe systems, the application rate is computed from lateral spacings and average flow into the lateral.

Infiltration Rate

The rate at which soil will take in water during the irrigation period; expressed in inches of water depth per hour (acre-inches per acre per hour).

Peak Moisture Demand

Peak moisture demand of any crop is considered to be the maximum that occurs during periods of maximum temperature and crop growth. This peak demand for moisture on the part of a crop results from transpiration by the plants and direct evaporation from the soil.

PART I — DESIGN AND PERFORMANCE

1. Application Rate

A portable sprinkler irrigation system, when properly designed

*Prepared jointly by the Sprinkler Irrigation Association and the Subcommittee on Sprinkler Irrigation of the Committee on Irrigation, Soil and Water Division, American Society of Agricultural Engineers. Officially endorsed by the Sprinkler Irrigation Association at its annual convention at Biloxi, Mississippi, in November 1952. Published in the Journal of the American Society of Agricultural Engineers and approved February 1953 as an official recommendation of the American Society of Agricultural Engineers.

and operated, should meet the following conditions with respect to water application:

a. Apply water at a rate which does not cause runoff during the normal operating period nor cause water to stand on the surface of the soil after the sprinkler line is shut off.

b. Determination of the proper rate of application *shall be the responsibility of the person designing the system.* Values for bare ground infiltration rates for different types of local soils may be obtained from responsible agricultural technicians. In the absence of such technical advice, the designer may estimate the proper application rate on the basis of past experience with similar soil types.

c. Modifications in infiltration rates because of cover conditions, such as straw mulch, cover crop, etc., should be made only at the request of the purchaser, who would then assume responsibility for maintaining such conditions.

2. System Capacity

a. For regularly irrigated areas—

The system shall have the capacity to meet the peak moisture demands of each and all crops irrigated within the area for which it is designed. Sufficient time must be allowed for moving laterals and for permitting cultural practices on the land. The capacity must also allow for reasonable water losses during application periods with the system operating in accordance with design conditions.

b. For supplemental irrigation and/or special uses—

The system shall have the capacity to apply a stated amount of water to the design area in a specific net operating time period.

3. Depth of Water Application

In the design of the system, total depth of application (equivalent rainfall) per irrigation shall be governed by the capacity of the soil for moisture storage and the depth of the principal root zones of the crop irrigated. Information on both of these factors may be obtained from agricultural technicians or may be estimated by the designer on the basis of his past experience with similar soil types and crops.

4. Uniformity of Water Application

Uniformity of water application is affected by both pressure in the line and sprinkler spacing. Sprinkler manufacturers can and do provide recommendations for desirable operating pressure and spacings for different types of sprinklers. These recommendations must be followed.

To assure reasonably uniform distribution the variation in pressure between any two sprinklers or sprinkler locations in the field to be served by the system shall not be more than 30 per cent of the higher pressure, regardless of whether the pressure difference is due to friction, surface elevation, or both. Exceptions to this rule must be confined to situations where conditions of excessive pressure differences occur for only a very short portion of the operation period.

5. **Crop Damage**

Water must be applied in a manner which will not cause direct physical damage to plants or fruit.

PART II — DEALER-PURCHASER RESPONSIBILITIES

1. **Dealer Responsibility**

a. **Proper Design**

When the system is planned by a dealer, or his representative, the dealer assumes full responsibility for the proper design of the system he proposes to furnish. Design requirements to fit the system to conditions of soil, topography, water supply and crop enterprise must be ascertained by the dealer either directly or by obtaining such information from recognized reliable sources.

When design requirements are furnished in writing by the purchaser, then the dealer's responsibility is limited to the design of the system to meet the stated conditions.

When plans and specifications are furnished in writing by the purchaser, the dealer's responsibility is limited to supplying equipment which will satisfy the requirements of the specifications furnished.

When the purchaser buys the system piecemeal, he absolves all dealers of responsibility for the performance of the system as a unit.

b. **Operating Instructions**

The dealer or dealers furnishing equipment required for a complete sprinkler system should furnish to the purchaser in writing, such instruments, performance charts and layout drawings as are required to insure proper operation, in accordance with design conditions and normal expected life for the type of equipment furnished.

c. **Performance Warranty**

When a dealer or associated group of dealers assumes responsibility for the design and installation of a sprinkler irrigation system, a warranty should be furnished, stating specially the performance expected for water application rate, capacity, rate of coverage for a specific design area serving specific crops and crop acreages as stated by the purchaser and mutually understood to be the basis of design.

Warranty should be based on trial of the system during operation under the range of operating conditions imposed on the system. The warranty should not be expected to cover any conditions encountered which were beyond reasonable control of the dealer either in design or installation. Values used for infiltration rate, peak use rate of moisture by crops, or capacity of soils to retain water for plants cannot be expected to be accurate for every local condition of soil. Evidence that the dealer has made reasonable efforts to obtain values from reliable sources should be sufficient reason to absolve him from responsibility if such values do not represent local conditions.

When a dealer or dealers assume responsibility for the in-

stallation of a system in accordance with specifications supplied by the purchaser, a warranty should be furnished, stating the performance expected as to friction loss in the system, pump and engine or motor characteristics and other pertinent data pertaining to the specifications.

d. **Equipment Warranty**

The dealer or dealers assuming responsibility for the installation of the system must furnish warranties covering the quality of material and workmanship of each piece of equipment furnished in accordance with the original manufacturers' guarantee, and provide for replacement of defective parts shown to have failed because of poor quality materials or poor workmanship.

e. **Maintenance and Repair Service**

Dealers selling sprinkler irrigation systems in a territory should maintain an inventory of replaceable parts and required equipment repair service. The extent of this available service should be such that users in the territory would be assured of reasonable service which would avoid crop loss due to shutdown of a system for replacements or repairs.

2. **Purchaser Responsibility**

a. **Operations in Accordance with Instructions**

The purchaser and user of a sprinkler irrigation system has to assume responsibility for failure of the system to perform properly if, after receiving all data furnished by the dealer, he fails to operate the system in accordance with all conditions assumed in the design of the system. To obtain the full life of all equipment, the user must observe the stated limits of operating conditions set forth by the manufacturer.

b. **Care and Maintenance Recommendations**

The purchaser must follow the dealer's recommendations for care and maintenance of the equipment. This applies to periods of use as well as non-use of the equipment.

Miscellany

Appendix D and References 18, 28, and 201 to 220 inclusive, give detailed information for sprinkler system design, but it is better to leave this to experts. Specifications to which these experts should conform are given in the preceding section.

The Sprinkler Irrigation Association, 1028 Connecticut Ave., N. W., Washington 6, D. C., will supply the names of manufacturers and dealers for any particular territory and will furnish other general information.

Porous Hose

Porous or eyelet canvas hose (References 4, 102, 153, and 154) has been used in Michigan for irrigating small areas. The

limited experience in the East with this method has not been satisfactory, especially with high prices for labor and cotton fabrics. It may be successful under special conditions. There is little waste of land and water, important items where they are expensive. No leveling of the land is necessary, and only limited extra pumping is needed to maintain pressure of 15 to 20 pounds per square inch in the hose.

CHAPTER VII

WATER REQUIREMENTS

In the majority of cases of skillfully supplementing rainfall in the East, enough irrigating water must be applied in a season to the root zone of the average crop to cover the ground from six to twelve inches, or in other words, each acre of land requires from one-half to one *acre-foot* of irrigation water in the root zone. A wet season and a water retentive soil may require less water and a very dry season more, particularly on well-drained porous soils with crops that need much water. In a few regions the requirements may be greater.

The usual irrigation will apply 1 to 3 inches of water at one time to the root zone, with 2 inches usually preferred. The amount applied may vary from one-half to several inches depending on the frequency of irrigation, the type of soil, the nature of the crop, the amount of rainfall to be supplemented, and the dryness and capacity of the soil reservoir.

When and How Much Irrigation

There are many variables governing the question of *when and how much* irrigation, and judgment must be developed through local experiment and experience.

To get the full values and the best yields from irrigation, the moisture content should preferably be kept between well (say 25 per cent) above the *wilting point* (when crops begin to wilt) and under (say 75 to 90 per cent) of the field capacity (the maximum water which the soil will hold available to crops). When a crop wilts, irreparable damage usually has occurred. Only in special cases should more than 10 or 12 days elapse between applications of water, either in rain or by irrigation.

On the other hand, too much water, as could occur with a heavy rain following an irrigation that had nearly filled the soil 100 per cent, can leach the plant nutrients from the soil, keep air out of the soil, and cause erosion. Eastern irrigators will not wish to pump and use too much water since they pay individually and directly for what they use.

The best past practice has been to apply water according to

the moisture content of the soil before it approaches a wilting point as determined by borings and samplings with a soil auger, a soil tube, electrical resistance, or by digging down 6 inches to a foot and pressing a ball of earth in the hand. If the ball is moist, there is usually enough water for crop growth at that time, but not necessarily several days later when irrigation reaches the crop. Skilled irrigators believe that irrigation for maximum production should be started when the soil moisture yet available is about 35 per cent of the maximum available storage (between field capacity and wilting), which is often about 4 inches; that is, when about 2 inches of irrigation will bring the soil reservoir to between 75 and 90 per cent of capacity.

Some irrigators prefer to have even more water in the soil reservoir.

The starting time is governed partly by local conditions and partly by the prospect of early effective rains. Forecastings of rain are becoming more reliable. In deciding when to start irrigating, it must be remembered that a week or ten days may be required to reach all of the field. Uniformity and depth of irrigation throughout the field must likewise be tested by sampling.

Although there are now available many devices for measuring directly or indirectly the percentage of soil moisture content, they may not yet be practical for most farmers. This is partly because many farmers will not take this precaution and partly because of the variations in small amounts of soil samples in different parts of a field. Since soils vary greatly, it is probable that only a poor approximation of over-all soil moisture can be secured with a reasonable number of field installations. Interpretation of the results is difficult.

The Thornthwaite Method

Perhaps the best eastern method for determining when and how much to irrigate is that recently developed and advocated by Thornthwaite after practical use (References 30, 32, 35, 36, 37 and 41) namely, to find the *evapotranspiration* of the crop (the depth of water evaporated and transpired or breathed) and to apply enough irrigation water and rainfall to replace it. Together these will supply the water needs without depleting the moisture reserve in the soil, keep the optimum amount of water in the soil, and thus maintain the best growth conditions which are otherwise impossible. Using Thornthwaite's method, supplemental ir-

rigation can be scheduled to keep soil moisture near the optimum level for any particular crop.

Starting with the soil reservoir either full or empty, the depth in inches of both rainfall and irrigation are added, and the evapotranspiration is subtracted, on a record or *bookkeeping* sheet which at all times shows the depth in inches of water stored in the soil reservoir and available to crops at that time. When the record drops below a pre-determined level, say the 35 per cent previously mentioned, irrigation is started unless rain impends.

Thornthwaite used his *potential evapotranspiration,* that is, what exists when the plant has adequate water available, as when under supplemental irrigation.

The procedure, described in the above references and made quite accurately from rainfall observations and a new inexpensive *evapotranspirometer* (which measures evaporation and transpiration), is the basis for scheduling irrigation at Seabrook Farms, the largest integrated truck farms in the East. It is probably the least known but the best theoretically and practically of all irrigation scheduling procedures. It wastes no water, requiring from 4 to 16 (average 9) inches annually of irrigation entering the ground. The best moisture conditions for maximum growth are maintained.

Because Thornthwaite's methods are revolutionary, the foregoing references must be studied to understand them, simple though they are. An inexpensive rainfall gauge and an inexpensive evapotranspirometer (References 30 and 36) are all the equipment that is necessary.

A "Rule of Thumb" Procedure

Ordinarily, an experienced farmer can tell without difficulty when his crops need water, but this may be only approximate or too late. A good *rule of thumb* is to apply water at the rate of one inch or a little more per week actually delivered to the root zone, rainfall and irrigation included, then to change promptly from this as experience, special conditions, and the previously mentioned theories indicate. For example, crops vary in their need for water and some soils retain water longer than others. It may take a week or more to irrigate an entire field; careful planning is required lest the crop wilt before irrigation can reach it. Usually less than the foregoing rate of applying water

will be necessary in the early life, or during the maturity, of a crop. More will be required during the periods of maximum growth, high temperature, high wind, low humidity, and prolonged dry weather, and for crops of a leafy nature.

Every effort must be made to have the right amount of water present at the right time to assure maximum growth; this has seldom been attained and steps in this direction will be profitable. These ideas are expressed in a slightly different and simpler manner for western farmers, whose judgments are not complicated by rain, by the U. S. Bureau of Reclamation in Reference 28 as follows.

Time to Irrigate

> The determination of the proper time to irrigate is largely a matter of judgment for most farmers. In areas where the values of crops produced are very high and the cost of irrigation water is also high, it has been found desirable to govern irrigation practice by actual determination of the moisture content in the soil. Only in specialized cases however, is it economically worth while to control the irrigation applications as closely as this. Even where laboratory facilities are available and the soil moisture can be accurately determined, there is still a considerable problem as to the exact degree of dryness which justifies irrigation.* Ordinarily, an experienced farmer can tell without difficulty when his crops need water. The difficulty is to foresee a few days in advance, the time that a crop will need water in order that irrigation may be started and the field covered before this need becomes serious. It is believed that, especially with farmers new to irrigation, there is more danger that irrigation will be postponed too long than that it will be given too soon. With normal soils, a very good idea as to the moisture condition can be secured by digging out a handful of soil from a depth of 6 inches or a foot. If this soil will form a firm ball upon being pressed in the hand, it indicates usually that sufficient water is available for crop growth. Heavy clay soils, however, will sometimes make a very firm ball when they are much too dry for the ordinary crop. With experience, most farmers can tell by the color of the crop whether it needs irrigation. With most crops, the leaves turn a dark bluish green at the time the crop begins to suffer for water . . . . .
>
> The whole object of irrigation practice is to apply a uniform quantity of water at each irrigation. It must be made certain that the soil is moistened to a satisfactory depth by the irrigation water. This can best be determined by digging down alongside a furrow or corrugation and noting whether the moisture has penetrated to the moist soil below the root zone. A moisture probe made from a round steel rod 4 feet long and one-half inch in diameter, having a T-handle and a blunt end, is very useful in determining the depth of penetration

*Author's Note—The foregoing four sentences apply more to the West, than to the East.

of irrigation water in many soils. The probe is pushed downward with both hands in the bottom of a furrow or corrugation until it strikes the dry, hard ground. In learning to use the probe on any particular field or soil type, it will be necessary to make a few trials by digging out the soil with a shovel and determining whether the probe has actually reached dry ground or has been stopped by a pebble or for some other reason. A soil auger also may be effectively used to determine the depth of penetration.

If the farmer finds that he has secured satisfactory penetration of his irrigation water at the higher spots in the field or near the lower end of the runs and has used approximately the quantity of water which he estimated was necessary to supply his crop with a small excess for unavoidable waste, he may be sure that he has done a good job in irrigating.

It must be reiterated that a careful scheduling of the time and amounts of supplemental irrigation is essential to the highest yields and the economical use of water.

The Irrigating Head

The flow of water used by a farmer in irrigating is known as the *irrigating head.* It is expressed in cubic feet per second, or in gallons per minute, of water at a field. A flow of one cubic foot of water per second, or 450 gallons per minute, will cover one acre to a depth of approximately one inch in one hour.

The best size of irrigating head for a particular farmer will be large enough to keep a good man occupied with irrigating and associated work, while not requiring a too large and expensive flow of water. Heads between one-half and two cubic feet per second will generally be satisfactory in the East. A good irrigator can handle much more water than a poor irrigator. The greater the care with which the land is smoothed or leveled (not necessary in hose, sprinkling, or spray irrigation), the better the devices for turning the water onto the land, the more porous the soil, and the flatter the slopes; the larger may be the irrigating head. Realizing that conditions vary greatly, the paragraphs immediately following will be a very rough guide in selecting an appropriate irrigating head for usual conditions. Conveyance losses are excluded and the flow of water is assumed to be available at the field.

With furrows, one full-time eastern (inexperienced) irrigator can ordinarily handle about one cubic foot of water per second at the field, and will apply the equivalent of one inch in depth of water to one acre in one hour. On many soils the permissible *infiltration* rate will be much less than one inch per hour, which

means that a lesser depth would be applied to more acres. Much smaller irrigating heads may be used, but the irrigator then needs other nearby work to occupy his spare time.

In flooding by the use of border checks, contour checks, level rectangular checks, and wild flooding, from one and one-half to several cubic feet of water per second may be handled by one full-time man under average conditions. It is difficult to flood with less than one and one-half cubic feet of water per second unless the checks are made smaller or the field ditches are spaced closer together than usual.

A full-time man sprinkling can handle about one and one-half cubic feet of water per second.

Where pumps are used and it is desirable to minimize labor, the pump capacity should be sufficient to furnish the quantities mentioned above, plus water conveyance losses. Smaller pump capacities or irrigating heads often make necessary the expenditure of more time and labor in applying the water.

With porous canvas hose, overhead spray, or rotary sprinkler systems, irrigating heads in extreme cases are as little as one-tenth cubic foot per second and are often less than one cubic foot per second.

The Economic Size of Project for Two Full-time Irrigators

By Sprinkling or Rows

Although each project must be planned to fit its special conditions, the following example will illustrate an economic plan to irrigate 60 acres by the furrow, row, corrugation, or sprinkling method. It would require two men irrigating full time.

An irrigating head, at the field, of one cubic foot per second (450 gallons per minute) will be used (a little more at the pump or source to allow for losses on the way to the field). This will supply about two and one-half inches of water at the field to 40 acres in seven 14-hour daylight days of actually flowing water.

Because of seepage in the field ditches, evaporation, deep percolation, wind, and waste, perhaps only one-half to three-quarters of the water reaches the plants (*field efficiency* of 50 per cent to 75 per cent). With these field efficiencies, the gross amounts indicated would suffice for many crops but not for the worst conditions.

Since crops in the East generally require only some six to

twelve inches of irrigation water in the root zone per season, although more in a few regions, 40 acres will be irrigated over some 28 to 56 days of 14-hour pumping scattered through the summer. The pumping plant and irrigating system then will be idle for the remainder of the season.

However, by diversification of the crops and by using Thornthwaite's planting schedule so that their greatest needs for water come at different times, more acreage, say 60 acres, may be irrigated in some 42 to 84 days of 14-hour pumping. Even greater depths of water could be applied by pumping more days or for longer daily periods, and there would still be time for moving and maintaining the equipment during the balance of the summer when rainfall is adequate.

It thus becomes apparent that, under the conditions stated above, and if an irrigating head of one cubic foot per second at the field is suitable for the project requiring two full-time irrigators, maximum economy of cost and labor will result in a diversified project of some 60 acres. Long pumping hours will be necessary only occasionally. Multiples of such a layout may be slightly more efficient, and smaller tracts less efficient.

By Sprinkling or Flooding

By a similar line of reasoning, for sprinkling or for flooding with an irrigating head of two cubic feet per second, a tract of the order of 120 acres will be a desirable size of project. Two full-time and very capable irrigators are required.

Other Viewpoints

Another way of looking at this would be to assume somewhat less depth of water used and somewhat less diversification. Here again one cubic foot per second should irrigate 60 acres and two cubic feet per second should irrigate 120 acres, always bearing in mind that these flows of water are at the field and do not include losses between the source and the field.

To be entirely safe under the worst conditions, which would occur rarely, an acreage less than 60 or 120 should be irrigated, especially for crops using much water; or the pumps then would have to be run for more hours per day or for more days. Pastures, a few crops, and certain regions or soils may require more water and the example given above should be modified accordingly. However, it is doubtful if additional expense would be justified

for these rare occurrences. An irrigation adviser should be consulted for each project.

A more customary way of computing the water required to irrigate a given acreage is shown toward the end of Appendix D.

Farmers generally increase their acreages after their initial installations and it usually pays to install somewhat oversize pumps and mains. This extra capacity assures plenty of water and permits a variation in scheduling the irrigating labor, often very important.

Where only smaller acreages and flows of water are available, irrigating heads of from one-tenth cubic foot per second upward may be indicated, and under such circumstances hose, sprinkling, and furrows are most useful. However, the total cost per acre, including labor, for irrigating on these smaller projects will be greater than on the larger projects, unless labor is available for the small projects at little or no cost.

CHAPTER VIII

WATER AND FERTILIZER TEAM UP FOR BETTER YIELDS

by

Dr. Malcolm H. McVickar

Chief Agronomist
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Many factors control plant growth. However, two of these limit growth more often than all the others combined. These are: (1) a lack of adequate moisture and (2) a lack of ample amounts of the so-called "plant foods" or "plant nutrients." Through supplemental irrigation, farmers can deal satisfactorily with the moisture problem. Likewise, by the addition of commercial fertilizer they can supply plant foods which otherwise might limit crop production. The combined use of irrigation and fertilizer opens up a new frontier for American agriculture. Together they present one of the greatest advances in modern times for growing more and better crops without expanding acreage.

Irrigation principles have been explained in detail in the other chapters in this book. Thus, this discussion will be confined to what fertilizers are and how they can be applied through the water medium to increase crop production. First, however, the student needs to know what plants require and how plants feed. These are essentials for understanding how fertilizers contribute to greater plant growth.

Essential Chemical Elements for Plant Growth

At present, 15 chemical elements are known to be required by a plant for normal growth and development. They are: hydrogen, oxygen, carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, manganese, boron, copper, zinc, iron and molybdenum.

Plants have three sources for obtaining these essential elements—the air, the soil, and water. The air provides, through carbon-dioxide, a source of both carbon and oxygen. Water, composed of hydrogen and oxygen, is a source of these two elements. Although the air carries large amounts of nitrogen, most plants cannot use it in the inert form in which it is present. Legume plants, with the help of the so-called nitrogen fixing bacteria, can

utilize some atmospheric nitrogen, but most plants depend upon the soil for nitrogen, and for eleven other essential plant food nutrients: phosphorus, potassium, calcium, magnesium, sulfur, manganese, boron, copper, zinc, iron and molybdenum. If sufficient quantities of these plant-food elements are not given up by the soil they must be added by man or production will be limited. In fact, a deficiency of any one of these elements, although all of the others are present in adequate amounts, limits production. Thus, all of the elements must be present in ample supply and in available forms for maximum growth.

Primary, Secondary and Trace Element Plant Foods

In the fertilizer industry nitrogen, phosphorus (referred to in the trade as phosphoric acid) and potassium (marketed as potash) are called primary plant-food nutrients. Calcium, sulfur and magnesium are referred to as secondary plant-food nutrients. Boron, copper, zinc, iron and molybdenum are the trace or minor plant-food nutrients.

It is usually one or more of the primary plant-food nutrients that most often limits production. Deficiencies of the secondary plant-food nutrients are more common than deficiencies of the minor plant-food nutrients.

Although this discussion is confined to the primary plant foods—nitrogen, phosphoric acid and potash, the principles are applicable to all of the plant-food nutrients.

How Plants Feed

Plants can absorb large amounts of carbon dioxide and small amounts of most other plant nutrients through their leaves, but the normal avenue of entry is through the tiny root hairs. These plant nutrients are taken up in water solution.

Water, in addition to providing a source of hydrogen and oxygen, therefore plays a key role in getting the nutrients into the plant. Once these nutrients are in the plant, water continues to be important, since the nutrients are transported from one part of the plant to another in a water solution. The close association of water and plant-food nutrient uptake is, therefore, not coincidental. An adequate water supply is necessary for efficient plant nutrient utilization; an ample supply of plant food is a "must" for efficient water utilization.

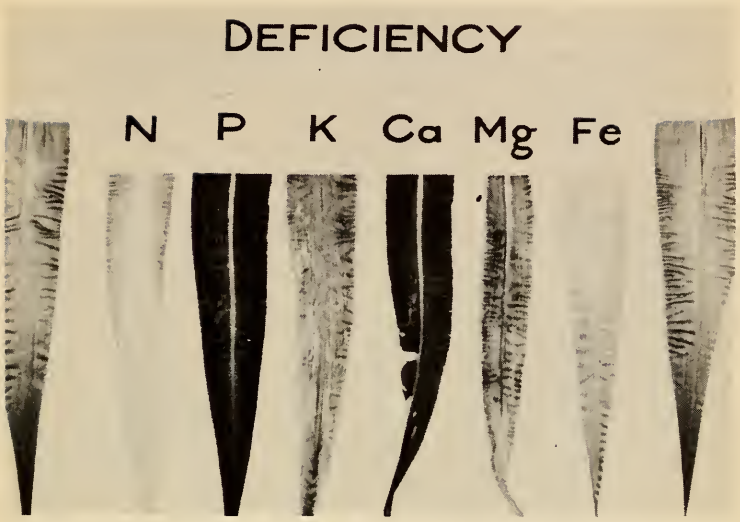


Fig. 23. Plants starving for plant food nutrients show definite "hunger signs." Here are the typical leaf symptoms on corn. From left to right: normal; nitrogen starved; phosphorus starved; potassium starved; calcium starved; magnesium starved; iron starved; and normal. (Courtesy Ohio Agricultural Experiment Station—National Fertilizer Association.)

Applying Fertilizers through Irrigation Water

Fortunately, many fertilizer materials can be applied to the soil through irrigation water. The application of fertilizers in this fashion has been practiced in the Western States for years. Although surface types of irrigation were developed first, it is clear from reports, research findings and farm experience that fertilizers have long been applied to the soil through sprinkler irrigation systems. In fact, this latter system has been used in California since 1930. Since supplemental irrigation in the East more often is sprinkler irrigation, the discussion is limited to this method of fertilizer application. Similar procedures can be used with surface irrigation.

With the development of lightweight aluminum pipe, the use of sprinkler irrigation has expanded rapidly, and so has the interest in the method and its potentialities.

Advantages and Disadvantages to Applying Fertilizer through Irrigation Water

There are good reasons for this interest. *First,* the application of fertilizer through sprinkler irrigation systems provides a means of doing two important jobs at one time. Both fertilizer and water can be put on in one operation with little more labor than required for just applying water. *Second,* a close control can usually be kept over the placement depth of nitrogen fertilizers that move freely in the soil. It should be pointed out, however, that the uniformity of fertilizer distribution is dependent on the uniformity of water distribution. Therefore, if the sprinkler system is improperly designed, poor fertilizer distribution as well as poor water distribution will result. This is one of the real problems involved in applying fertilizer through sprinkler irrigation. *Third,* a sprinkler irrigation system provides plant nutrients in solution—the form in which they are absorbed by the roots.

There are, however, some disadvantages to applying fertilizers through irrigation water. *First,* since the fertilizer must be water-soluble, some materials, oftentimes the cheapest forms, cannot be used. *Second,* localized fertilizer placement cannot be achieved. For example, it is impossible at corn planting time to follow the usual recommendation for putting the starter fertilizer in a band to the side and below the seed, a practice which keeps the fertilizer from coming into contact with the seed and possibly affecting germination adversely. Nevertheless, fertilizer irrigation places plant-food nutrients close to the tiny plants and easily available for their use. Such placement contributes to the economy of fertilizer use on row crops.

A third disadvantage of applying fertilizer through irrigation develops when materials containing phosphoric acid are used. If applied in the water they will concentrate near the surface—not in the root zone where they should be for best results. If deep placement is required, the only way to do the job is to employ mechanical methods. One can't rely on phosphatic plant food being carried down by irrigation water.

Method of Applying Fertilizers through Irrigation Water[1]

One of the simplest and most common ways to inject fertilizers into a sprinkler irrigation system is by the use of the so-

[1]The author has drawn heavily on material presented by James E. Ferguson at the Annual Meeting of the National Fertilizer Association, White Sulphur Springs, West Virginia, June 15, 1953.

called "two-valve" method. A valve and hose is provided on the discharge side of the pump to supply water to a 55-gallon drum where the fertilizer is mixed with the water. A second valve and hose is provided on the suction side of the pump through which the mixture is drawn into the system. The rate of intake is adjusted by means of the valve on the suction side of the pump.

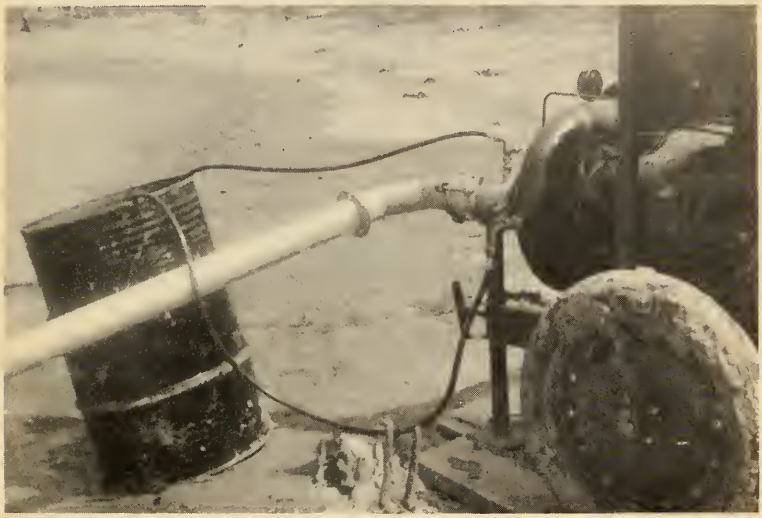


Fig. 24. Injecting fertilizer into an irrigation system using the so-called "Two-Valve" method. (Courtesy, J. E. Ferguson, Southern Irrigation Company.)

Another method of applying fertilizers through a sprinkler irrigation system involves the use of a Venturi tube placed in the discharge pipe line. This method is applicable to any system regardless of the type of pump used. The Venturi tube is connected by means of a pipe to a closed supply tank, thus forming a circuit for water flow from the main pipe line to the Venturi throat, or small part of the tube. Positive displacement pumps are sometimes used to inject the fertilizer-water mixtures into the sprinkler system. This may be particularly applicable when the system is operated from a deep-well turbine pump.

Fig. 25. Injecting fertilizer into an irrigation system using the Venturi method. (Courtesy, P. F. Dragon, Dragon Eng. Co.)

Time Intervals in Applying Fertilizers

The recommended procedure followed in applying fertilizers through a sprinkler irrigation system usually is divided into three time intervals. During the first period, just plain irrigation water is pumped through the system. During the second interval, which normally should not be less than a half hour, the fertilizer-water solution is injected into the system. If this amount of time is allowed, the possibility of poor distribution due to slow and uneven rotation of older sprinklers is eliminated. Also, at normal fertilizer application rates, the fertilizer-water mixture passing through the system is so dilute as to practically eliminate any possible foliage burn. Likewise, such a dilute fertilizer solution reduces corrosive effects on the irrigation mechanism.

During the third and final time interval plain water again is the only material pumped through the pipes. Sufficient water should be applied during this interval to completely rinse the system and to remove all fertilizer from the plant foliage.

Quantities of Fertilizer to Apply

No more than five pounds of fertilizer per 100 gallons of water should be applied through a sprinkler irrigation system. The following equation can be used for calculating the amount of fertilizer to be injected into the sprinkler irrigation system for each set or position of the sprinkler laterals.

$$P = \frac{(L \times W)(R)}{(43560)}$$

P = Pounds of fertilizer injected per lateral set
L = Length of lateral
W = Width between successive lateral positions
43560 = Square feet per acre
R = Desired rate of fertilizer application in pounds per acre

Of course, the amount of fertilizer to be applied per acre will depend on the particular soil involved, on the fertilizer material being applied, and on the crop itself. Since the amount of plant food removed by different crops furnishes some guide as to the quantity which must be present, there is a relationship between the requirements and fertilizer application recommendations. The amount of fertilizer plant-food nutrients removed by some of our more common farm crops is given in Table IV.

TABLE IV
PLANT FOOD NUTRIENTS REMOVED BY COMMON FARM CROPS

Crop	Yield	Removal—Pounds of		
		N	P_2O_5	K_2O
Alfalfa Hay	4 tons	187*	47	180
Apples	400 bu.	20	7	30
Barley (Grain)	60 bu.	53	23	15
Beets, Sugar (Roots)	20 tons	73	29	71
Cabbage	15 tons	100	25	100
Celery	350 crates	80	65	235
Clover, Red	2 tons	80*	20	70
Corn (Grain)	100 bu.	78	36	26
Corn (Stover)	3½ tons	52	19	94
Corn (Grain and Stover)	100 bu.	130	55	120
Cotton (Lint and Seed)	1⅓ bale	57	27	21
Grapes	4 tons	10	6	20
Lespedeza Hay	3 tons	130*	30	70
Oats (Grain)	75 bu.	53	23	15
Oranges	600 boxes	65	23	105
Peaches	500 bu.	30	15	55
Peanuts (Nuts)	1 ton	60*	10	10
Potatoes, Irish (Tubers)	500 bu.	108	42	192
Potatoes, Sweet (Roots)	500 bu.	75	25	125
Soy Beans (Grain)	40 bu.	176*	56	64
Spinach	9 tons	90	30	45
Timothy Hay	2 tons	53	20	60
Tobacco	2000 lbs.	73	13	106
Tomatoes	10 tons	60	20	80
Wheat (Grain)	40 bu.	47	21	12

*Legumes obtain a part of their nitrogen from the air.

Suitable Fertilizer Materials

Many fertilizer materials are on the market today, differing not only in type but also in plant-food nutrient content. Some carry only one of the primary plant-food nutrients; others carry two; while complete mixed fertilizers furnish all three. In addition, the corrosive qualities of the different fertilizer materials vary, making some more suitable than others for application through sprinklers.

Table V gives the percentages of total nitrogen, available phosphoric acid, and potash carried by most of our commonly used soluble fertilizer materials. Some information on the corrosive qualities of certain fertilizer materials is presented in Table VI.

TABLE V

AVERAGE NITROGEN, AVAILABLE PHOSPHORIC ACID, AND POTASH CONTENT OF SOME COMMONLY USED FERTILIZER MATERIALS

Fertilizer Material	Total Nitrogen (percent)	Available Phosphoric Acid (percent)	Water Soluble Potash (percent)
Ammonium nitrate	33.0	—	—
Ammonium phosphates	16.0–11.0	20.0–48.0	—
Ammonium sulfate	20.5	—	—
Anhydrous ammonia	82.2	—	—
Aqua ammonia	24.6	—	—
Calcium nitrate	15.5	—	—
Calnitro	20.5	—	—
Cyanamid	22.0	—	—
Liquid phosphoric acid	—	52.0	—
Muriate of potash	—	—	50.0–62.0
Nitrogen fertilizer solutions	37.0–49.0	—	—
Nitrate of soda	16.0	—	—
Sulfate of potash	—	—	48.0–52.0
Sulfate of potash-magnesia	—	—	22.0
Superphosphate (Normal)	—	18.0–20.0	—
Superphosphate (Concentrated)	—	40.0–48.0	—
Urea	42.0–45.0	—	—

TABLE VI
RELATIVE CORROSION OF VARIOUS METALS[a] AFTER FOUR DAYS OF IMMERSION IN SOLUTIONS OF COMMERCIAL FERTILIZERS[b]

Kind of Metal	Calcium Nitrate	Sodium Nitrate	Ammonium Nitrate	Ammonium Sulfate	Urea	Phosphoric Acid	Di-ammonium Phosphate	Mixed Fertilizer 17–17–10[c]
Galvanized Iron	2	1	4	3	1	4	1	1
Sheet Aluminum	0	2	1	1	0	2	2	1
Stainless Steel	0	0	0	0	0	1	0	0
Phospho-Bronze	1	0	3	3	0	2	4	4
Yellow Brass	1	0	3	2	0	2	4	4
PH of Fertilizer Solution	5.6	8.6	5.9	5.0	7.6	0.4	8.0	7.3

Nitrogen Materials

Ammonium Nitrate. This 33.0 per cent solid nitrogen material carries one-half of its nitrogen in the ammonium form and the other half in the nitrate form. It is completely water soluble, making it satisfactory for application through sprinkler systems.

Ammonium Phosphates. The three most commonly used ammonium phosphates are 16-20-0 (commonly called ammonium phosphate-sulfate), 11-48-0 and 13-39-0. The first figure in the formula refers to the percentage of nitrogen; the second figure to the percentage of available phosphoric acid. The 0 indicates that these materials carry no potash. All three of these ammonium phosphates are water soluble. They are considered ideal for supplying both nitrogen and phosphoric acid through irrigation water.

Ammonium Sulfate. Ammonium sulfate carries approximately 20.5 per cent nitrogen in the ammonium form. In addition to nitrogen, this material supplies sulfur. Because of its sulfur content it leaves an acid residue which is desirable on soils with a high pH value. It is entirely satisfactory as a nitrogen material for distribution through sprinkler irrigation systems.

Anhydrous Ammonia. This very concentrated nitrogen mate-

0—None; 1—slight; 2—moderate; 3—considerable; 4—severe.
[a]Metal sheets stood in fertilizer solutions 4 days prior to demonstration.
[b]Solutions by dissolving 100 pounds material in 100 gallons water.
[c]A commercial mixture made by mixing ammonium sulfate, di-ammonium phosphate, and sulfate of potash.
Source: Martin, W. E., Extension Soils Specialist, University of California. "Do Fertilizers Ruin Sprinkler Systems?", a talk presented before the Irrigation Sprinkler Conference, January 30, 1953.

rial is actually a gas, but it is stored under pressure as a liquid. When released from storage pressure, anhydrous ammonia reverts to its gaseous form. Currently, there is considerable controversy as to the use of this nitrogen fertilizer for application through sprinklers. Results of tests in Georgia by Carreker [1] with anhydrous ammonia showed severe plant burn. Also, there was a loss of 75 per cent of the nitrogen from the solution discharged by the sprinklers and that which was collected as the solution hit the ground. On the other hand, many authorities who are well informed on the reactions of anhydrous ammonia believe that this nitrogen material can be successfully distributed through sprinkler systems. However, until methods have been proven, most irrigation technicians will likely refrain from recommending the application of this form of nitrogen through sprinkler irrigation systems.

Aqua Ammonia. This nitrogen carrier is simply a saturated solution of ammonia in water. Contrasted to anhydrous ammonia, aqua ammonia can be stored in ordinary tanks since it exerts little or no pressure. Being in solution, it can be easily injected into the water stream of the irrigation system. Problems of loss and leaf burn may be similar to those experienced with anhydrous ammonia.

Calcium Nitrate. This nitrogen fertilizer, carrying both nitrogen and calcium, is imported into the United States. Because of its rather low nitrogen content, a larger amount of this material must be used than of the higher nitrogen fertilizers. Its continued use tends to raise the pH value of the soil.

Calnitro. This product is essentially ammonium nitrate plus dolomitic limestone. One-half of the nitrogen is in the ammonia form and the other half in the nitrate form. In addition to nitrogen, Calnitro furnishes calcium and magnesium, and is considered a very good source of nitrogen.

Cyanamid. This is a specialty nitrogen material. When applied to the soil it undergoes certain chemical changes, and the intermediate products formed are harmful to germinating seeds. When used for field crops, cyanamid should be put in well in advance of planting time. Although used extensively for weed control on tobacco beds, and also for defoliating of cotton and soybeans, prospects of its use in sprinkler irrigation systems certainly appear to be very limited.

[1] Carreker, John R., College of Agriculture, University of Georgia, 1949 Annual Report.

Nitrate of Soda. The use of nitrate of soda, which carries 16 per cent of nitrogen, lessens the need for lime. It is best suited, therefore, for use on acid soils. Under certain conditions, the sodium in nitrate of soda appears to substitute for potash to a limited degree. Being water-soluble, this material can be applied through sprinkler systems.

Nitrogen Fertilizer Solutions. These materials are normally used by the fertilizer manufacturer to make complete mixed fertilizers. Most contain some free ammonia which causes the same problems discussed under "Anhydrous Ammonia" above. Those materials, composed largely of ammonium nitrate and urea, are, however, being used satisfactorily in sprinkler irrigation systems.

Urea. This high nitrogen fertilizer material is water-soluble and is ideally suited for distribution through irrigation systems. In fact, research has shown that the plant can assimilate urea nitrogen in small amounts through the leaves. The spray method of application is fairly common in orchards where a delicate nutrient balance is necessary for fruit color. When applied to the soil, urea is quickly converted to ammonia and to the nitrate forms which can be taken up by the plant roots.

Phosphoric Acid Materials

Ammonium Phosphate. These materials have already been discussed under Nitrogen Materials. They are highly prized for irrigation application.

Superphosphate (Normal). Normal superphosphate, the most common of all phosphoric-acid-carrying fertilizer materials, is made by treating finely ground phosphate rock with sulfuric acid. The acid converts the insoluble phosphate to a more available form. Normal superphosphate contains large amounts of gypsum which has a fertilizer value under alkaline soil conditions. Unfortunately, however, the gypsum is insoluble in water, which makes its distribution through sprinklers somewhat difficult. If the material is mixed in a drum and then left so that the gypsum will settle out, a fair distribution is possible of the liquid which contains practically all of the phosphoric acid.

Superphosphate (Concentrated). This material varies from normal superphosphate in that most of the gypsum has been removed. It is, therefore, more concentrated than normal superphosphate. The removal of the gypsum also makes it easier to

dissolve it in water and inject it into the water stream of the irrigation system. The ammoniated forms of either normal or concentrated superphosphate are not suitable for application through sprinkler irrigation systems.

Potash Materials

Muriate of Potash. There are two grades of muriate of potash, one carrying approximately 50 per cent potash and the other approximately 62 per cent potash. Both grades are water-soluble and can, therefore, be injected into the water stream of a sprinkler irrigation system.

Sulfate of Potash. This material is of particular value for crops where an excess of chlorine is harmful to quality. It is water-soluble and can be satisfactorily distributed through a sprinkler system.

Sulfate of Potash-Magnesia. In addition to furnishing potash, this fertilizer material also supplies magnesium, one of the secondary plant-food nutrients. It is ideally suited for crops requiring ample quantities of soluble magnesium. Being water-soluble, it can be distributed by irrigation methods.

Mixed Fertilizers

There are many different mixed fertilizers. What's more, a mixed fertilizer of a given plant-food content can be made from a wide variety of fertilizer materials. Some of these are completely water-soluble while others are not. It is impossible, therefore, to give any definite statements as to the suitability of mixed fertilizers for distribution through irrigation systems. This much can be said, however—that if the fertilizer is composed completely of water-soluble materials, it can be applied through the water stream.

Several complete mixed liquid fertilizers are on the market and the farmer should remember that a pound of plant food is a pound of plant food whether it be in liquid or powdered form. If the price of the plant food in the liquid form is in line with that in dry forms then there are no objections to liquids. The liquids, of course, can be injected into the sprinkler system with ease.

Development of the New Agricultural Frontier

To summarize, the use of supplemental irrigation coupled with the wise use of fertilizer opens a new frontier for American agriculture. Farmers are now afforded an opportunity to grow bigger crops of better quality on their acres. Net result: Higher yields which reduce the unit cost of production and thus contribute to a more efficient agriculture.

Many problems need further study, but these will be solved through the combined efforts of research agencies and private industry. With the rapid increase in the number of irrigation systems, improvement in fertilizer technology and in the know-how of applying plant food nutrients through irrigation water, more abundant and efficient production on our farms can be anticipated.

CHAPTER IX

COSTS AND PROFITS

Since each supplemental irrigation development is highly individualized and presents many variable factors and conditions, it is impossible to give generally applicable data on costs and profits. Each project must be planned and estimated separately.

Cost of Pumping

This is given in Appendix C.

Total Irrigating Costs

Appendix C mentions the power cost of pumping only, not the total cost of irrigation. Much the larger part of surface irrigation expense, both for original cost and for annual cost, is incurred for labor and farm equipment use which may not involve a cash outlay. On the other hand, sprinkling systems require less labor and more cash. The costs given subsequently are *total irrigating costs,* including labor, farm equipment use, pumping and other costs of securing the water; and interest, taxes, insurance, and depreciation on the original cost of investment.

As stated heretofore, each project must be planned and estimated individually, and consequently it is impossible to give here cost figures that will suit a particular project. However, the following will furnish a rough idea of 1954 costs of irrigation to those not familiar with such practices. Costs for an unusual case may be lower or higher. It must be reiterated that costs per acre are generally much higher on small areas (say under 20 acres) than on large areas (say over 60 acres).

Total Original Cost

The average original complete cost of installing supplemental irrigation on a large, well-planned project in the East may be in the neighborhood of $60 to $125 per acre, occasionally outside of these limits.

Total Annual Cost

The annual fixed cost of keeping the irrigation installation

ready to serve whether used or not, consists of interest, depreciation, taxes, and insurance totaling 7 to 10 per cent annually of the original cost, or from $5 to $12 per acre per year. This permits the higher type of crop culture and yields that are possible with an assured water supply, and in addition may be considered in the nature of an *insurance premium* for protection against droughts, against decreased yields where rainfall is poorly distributed, and against interruptions in the permanent farm and livestock program caused by uncertain yields.

Each year that irrigation is used considerably, and this will be most years for most crops, the total annual cost for each acre, including the *ready to serve* annual costs of the preceding paragraph, may be from $20 to $25, occasionally outside these limits. The average cost per acre over many years will be less since wet years will occur, but the larger yields will be secured every year.

Irrigation costs throughout the arid West are much greater than those for the East as are transportation costs, land values, and taxes. The scattered irrigation of the East is much less vulnerable to bombing than is the concentrated stored irrigation water of the large projects in the West.

Comparison of Sprinkling with Surface Costs

These are given on pages 48 through 51.

Profits

Of great importance as a long-time profit is the increased value and marketability of farms after they have been placed under irrigation. It is entirely conceivable that non-irrigated crop land will begin to depreciate in value in the next decade while irrigated land will increase greatly.

Because conditions vary so widely and because of changing costs and prices, it is not often possible to find data on annual profits that can be transferred readily and with confidence to a new and different situation. In general it would appear that well-planned and well-executed supplemental irrigation will earn in crop value now (much more as irrigation practices improve) 100 per cent on annual expense thereof and, in addition, will serve as insurance against severe losses and interruptions of the farm and livestock program caused by low yields and droughts, big and little.

Truck and special crops often are the most profitably

irrigated (see the References or visit truck farms near the larger cities), but they are too numerous and too variable to describe here.

Taking corn as an example of field crops, the average yearly irrigation on an efficient project over wet and dry years may cost $20 per acre total (including interest, depreciation, taxes, insurance, use of farm equipment, labor, supplies, power, etc.). While the total cost of putting in the crop (including heavier fertilization and increased plant population) will be greater, the cost per bushel will not be greater since the yield will be increased.

In return for this annual expense, an average yearly increase should be secured of 40 bushels or more per acre. Colonel C. R. Pettis (Reference 66) and most informed persons believe that the increased yield will exceed this figure, attaining a total average yield of much over 100 bushels per acre as compared with a U. S. average of 35 and peak state averages of around 60. In addition, there would be assurance against droughts and low yields which interrupt the regularity of the farm business, as for example, a livestock program may be interrupted because valuable herds must be sold on a demoralized market. A farmer can no more afford these interruptions, such as occurred in 1952, 1953, and other drought years, than can an efficient manufacturer.

Throughout the References will be found example after example where the profit on all kinds of crops exceeded 100 per cent on the annual cost of irrigation, without benefit of the latest developments.

In the *Yearbook of Agriculture, 1943-1947*, an example is given by L. M. Ware of the Alabama Agricultural Experiment Station. Sweet corn failed completely in a field at Auburn, when no commercial fertilizer was used, he reported in 1945; the plant food in the soil was inadequate to support corn production. But when a commercial fertilizer was added, a yield of corn valued at $153 an acre was obtained. When a commercial fertilizer was added and the corn irrigated, a crop was produced that had a value of $253 an acre. When a commercial fertilizer and manure were added, the crop was valued at $439.50 an acre. When a commercial fertilizer and manure were added and the corn was irrigated, a crop was produced that had a value of $553 an acre. When commercial fertilizer and manure were added, a crop of vetch was turned, and the corn was irrigated, a yield was

produced that had a value of $699.50. Each fertility factor artificially helped to provide more nearly the optimum conditions for corn production. The effect on the yield of corn was cumulative. When all factors were supplied, a yield of 13,845 pounds of marketable green corn was produced. Reference 62 gives a similar but later experiment with similar results.

Many other examples of the increased quality and quantity of yields are found throughout the literature of supplemental irrigation. However, most of the reports are conservative since the full advantages of irrigation had not been obtained. The future will see greatly increased yields and profits as the present knowledge of crop scheduling, of irrigation, of fertilization, of close planting, and of strains adapted to irrigation is put to work under expert advice and with cooperation among the irrigators.

CHAPTER X

CONCLUSIONS

Most of the conclusions may be inferred from the preceeding pages, but a brief summary is presented here.

Supplemental irrigation has been practiced satisfactorily in various portions of the United States since 1900, and recently the procedures and techniques have been developed sufficiently to justify great expansion and to ensure increasingly profitable results throughout the East. Vegetables and truck crops, orchards, small fruits, corn, alfalfa, rice, most other crops, and irrigated pasture all give increased profits under proper irrigation and market conditions. Rice must be raised in standing water but other crops may be irrigated either by sprinkling or by surface methods.

Advantages. Irrigation in the East should be viewed only secondarily as insurance against bad droughts, but mainly as a method of increasing the yield and value of crops in all years and making possible an uninterrupted farm program. It will provide a self-liquidating type of investment for the surplus funds in the hands of farmers, and it will permit satisfactory loans for banks and insurance companies.

The eleven points enumerated on pages 24 and 25 make irrigation more promising than in the past. The East possesses competitive advantage for irrigation over many western arid regions because rainfall supplies most of the needed water; because water-right, water-table, and drainage problems are at a minimum; because the country is settled and developed; and because it has larger and closer markets. A doubling of crop yields or a return of 100 per cent on the annual cost of irrigation will often be realized.

Requirements. Supplemental irrigation should be used only on satisfactory soils, with proper topography, with good drainage, with a long-term water right, and with a reasonable irrigating cost. It should also be directed toward satisfactory markets, performed under experienced direction, and installed permanently. It does not pay to irrigate for a dry year or two and then abandon the idea. A halfhearted attempt is doomed to failure. On

the other hand, the scientific irrigated farming of the future will far surpass that of the present.

Experience shows definitely that use of proper fertilizers must usually go hand in hand with irrigation if the maximum returns are to be obtained. Also, strains and spacing of plants adapted to irrigation must be used, and scheduled balanced farming with weed and pest control is frequently advisable.

It is necessary that controlled experiments and demonstrations be established in the East and continued without interruption over wet and dry years to accumulate local data for irrigation and to demonstrate good practices. Programs similar to those of References 6, 8, 13, 23, 30, 32, 34, 37, 59, 63, 71, and 217 will suffice.

The advancement of supplemental irrigation will best be accomplished through the interest and efforts of groups and organizations, as it has been in most of the successful irrigation developments, rather than by individuals. Organizational procedures that have realized benefits in the West must be adapted and used in the East. National associations such as those of the fertilizer and sprinkler manufacturers will be helpful, as will be the manufacturers of pumps and pipe. Much promotional cooperation among the interested parties will be necessary. It is hoped that this book will provide an informational basis that will encourage the growth of scientific supplemental irrigation.

Larger Acreages Desirable. Larger acreages will generally cost less per acre for irrigating than will smaller acreages. Furthermore, because of the greater community interest in common problems among more people on larger developments, the larger acreages will usually produce more marketable and more profitable crops. Smaller acreages may be irrigated profitably under special conditions if carefully planned.

Cooperation. Successful irrigation throughout the arid West often has involved blocks of land of from several thousand to a million acres. In most cases the development has been supervised by federal and state governments or by large corporations and the whole undertaking, including the actual irrigation and farming, has attained the efficiency which characterizes large enterprises. In the East, supplemental irrigation will be done on relatively small and isolated areas; nevertheless, it will be necessary to attain similar efficiency. It is essential that the group action characteristic of older, successful irrigated districts be

encouraged in the East so that these cooperative practices may be established and extended and modified to fit the local situation.

A Single Plant for Several Farms. In cases where portable pumping plants are practicable, a group of farmers may own such a plant as well as the necessary pipe and accessories, and may arrange among themselves, perhaps as a water district, for the irrigation of such parts of their farms as may be agreed upon.

Alternatively, a farmer or a well-drilling contractor may secure this equipment and rent it to others, preferably operating the plant and directing the irrigation because of his experience in these matters. This is analogous to present practices in renting tractors and other farm machinery.

In the Spokane Valley, Washington during 1949, 30 small farms in a suburban area comprising 490 acres completed a single pressure-pipe system with sprinklers on all their farms, replacing surface systems. It has proved quite satisfactory. More of this sort of thing will be done near cities and towns where such a system could supply domestic water, fire protection, and irrigation to even smaller suburban homes or to country estates (Reference 215).

Promotion. It is expected that some of the most successful irrigation will result where large tracts of land are irrigated.

Much western promotion of irrigation has been conducted by chambers of commerce or similar responsible bodies which have convinced their members that expansion of irrigation in the territory tributary to their cities would bring much new business to them, thus repaying their promotional activities handsomely. The chambers have often arranged for a full-time promoter, expert advice, and loans from banks, insurance companies, and governmental agencies.

Irrigation equipment dealers should interest their chambers of commerce and perhaps themselves become the expert advisers or promoters.

Often a real estate group or a promoter will acquire several thousand acres, install irrigation, and subdivide and sell the larger tracts to farmers and the smaller ones for business and suburban homes or estates, perhaps furnishing irrigation, domestic water, and fire protection from the same jointly or privately owned system.

Promoters should popularize supplemental irrigation as a

new and improved way of life, as this idea has been capitalized for many years in the West.

An irrigated truck and fruit growing corporation with packing, canning, and freezing facilities will aid diversification, provide marketing, and give a good load factor for the entire operation because of centralized and scientific scheduling and management, as on page 16. Other types of irrigated corporation farming may prove successful if the labor problem can be solved.

Since pump, pipe, fertilizer, and sprinkler companies are interested in selling their products, and power companies are interested in selling their power, they all are active in promoting supplemental irrigation.

Subsidies. Because of the officially declared *drought disaster areas* of recent years, it is probable that advice, and perhaps subsidies, may be forthcoming from state and federal agencies. The availability of competent education, advice, and research, and of experimental and demonstration units under such auspices, are *musts* for successful irrigation. They should be subsidized.

The establishment of a few typical owner-operated irrigated farms under subsidy and with the technical advice of federal, state, and local agencies will greatly speed the growth and effectiveness of supplemental irrigation. Reference 23 explains such a modern setup which takes into account the whole, balanced farm management program, not simply plot studies, and serves as a down-to-earth demonstration farm.

Competent Education and Advice Essential. It is especially important that the isolated, individual farmer have expert advice since he is not skilled in the complexities of planning necessary for modern irrigation; since he will not have irrigating neighbors to advise him; since he may attempt to economize too much in installing and operating his irrigation; since he may not increase his plant population and fertilization adequately; and since he will be tempted to abandon his irrigation too easily. Once abandoned, it is difficult to re-establish.

The irrigating head, the capacity of the pump and of the distributing system, the economy of pumping, the economical use of irrigating labor, the amount of acreage to be irrigated, the diversification and rotation, the plant population, the use of fertilizers, and scheduled balanced farming and weed and pest

control must all conform to a comprehensive plan if a particular project is to give maximum returns. Informed participation has nearly always been the basis for the best irrigation. Without it, the irrigation may be abandoned with consequent loss and dissatisfaction, as has often happened in older irrigated districts.

Many questions arise in the mind of one contemplating irrigation for the first time. Competent education and advice are essential before any extensive development is started. The latest information must be understood, such as the crop and irrigation scheduling of Thornthwaite. Irrigation is undertaken for profit, and poor planning or execution may reduce these profits, sometimes to the vanishing point. While sound irrigation practices are pretty well established, they are constantly being improved, and irrigators must keep abreast of the times. Teachers of agriculture should lead in spreading the facts regarding supplemental irrigation.

The *1943-47 Year Book of Agriculture* states that:

> The irrigation farmer should not be content with water to eliminate the hazard of drought . . . . . On any farm at whatever level of soil fertility, maximum plant growth cannot be obtained if moisture is a limiting factor. Where moisture and plant nutrients are supplied in adequate amounts, the highest production will be obtained only when there are enough plants to utilize fully the space available for growth. It is only when the best combination of various practices is obtained that the farmer may expect a maximum yield.

The final word is: do not start supplemental irrigation without the best advice, without the determination to do a thorough job such as is done on the better eastern and western projects, and without keeping in touch with the latest knowledge which should be available through teachers of agriculture and other advisers.

Appendices

APPENDIX A

HOW TO GO ABOUT STARTING IRRIGATION

These statements use the personal pronouns for emphasis.

I. With the advice of your expert, decide definitely whether you wish to enter wholeheartedly into a more modern and more productive type of agriculture involving considerable expense and labor but with much larger and more assured crops every year.

Make your plans many months before planting time. Advice, materials, and time for installation are available then. Due to the rapid growth of supplemental irrigation, equipment must be ordered well in advance. War can interrupt deliveries. After the crop is planted or dry weather sets in, it is too late.

II. Ask your teacher of agriculture or your county agent to recommend a competent irrigation adviser. He may be a local man, a representative of your state Agricultural College, a Soil Conservation Service man, or other experienced person. It may be wise at this time to avoid those with something to sell you. Your dealings with them come later. Work closely with your adviser.

III. Secure a good one-foot contour map for surface irrigation on flatter topography or one with less detail on it for sprinkling.

IV. Decide what fields you wish to put into what crops over the next fifteen years (the probable life of your equipment), allowing for rotation and for scheduled balanced farming. This will influence your irrigation planning, especially your leveling for surface irrigation and the capacity of your water supply and distribution system.

V. Try to plan a diversification and scheduling of crops so that your entire irrigated acreage will not usually need water badly at the same time. Your water supply then will irrigate more acres, or irrigate for shorter hours daily, or assure a more adequate supply of water in very dry weather.

VI. Select your water supply and method of getting the water from the source to the fields (see Chapter III and Appendix F).

It may be desirable to install a pump and pipes large enough for future expansion and for altered plans. The majority of farmers expand their irrigated acreage.

If you are to use electricity, contact your electric power company regarding your power line and your pumping power rate.

If a well is needed, a reliable local well driller must be selected and consulted as briefly mentioned on page 38. In a few cases the state geologist should be consulted, perhaps by letter. Assure yourself that your right to the water will not be successfully contested.

VII. Decide whether your labor will irrigate on a *full-time* or an *odd-job* basis and how you will schedule their time. This will vitally affect the design of your irrigation system.

VIII. Decide whether you will use surface irrigation or sprinkling. If the latter, invite complete proposals from dealers for the entire pump and sprinkler system in place. Make the dealer completely responsible for the whole installation and its operation according to the specifications on pages 84 through 87. The dealers nearer you are often preferable since service and repairs will be more quickly available.

IX. If surface irrigation is preferred, then a layout of ditches and leveling must be made for you by a competent irrigation adviser as described in Chapter V and Appendixes E and F.

X. Remember that crops and strains other than the usual ones may be better adapted to irrigation. Consult your crop adviser as to the crop, the strain, the expected yield, the plant population, fertilization, etc.

XI. Get everything planned and all necessary construction and leveling done before the crops are planted.

XII. Irrigate as suggested by your adviser, keeping in touch with the local station of the Weather Bureau.

XIII. Cooperate with your agricultural college on a few test plots.

XIV. Discuss your results with your adviser and plan to improve the operation next year. Growing conditions are now largely under your control.

APPENDIX B

GLOSSARY

Units of Measurement

A *gallon* of water contains 231 cubic inches and weighs 8.35 pounds.

A *cubic foot* of water contains 7.48 gallons and weighs 62.5 pounds.

An *acre-foot* of water is the amount necessary to form a layer of water one foot deep over one acre. It is equal to 43,560 cubic feet, or 326,000 gallons.

An *acre-inch* equals 1/12 of an acre-foot. It is equal to 3630 cubic feet, or 27,154 gallons.

One *pound of pressure* is created by a column of water 2.3 feet high. As an example, if the pressure gauge on a pump reads 10 pounds, then the pump is working against friction and lifting equivalent to a straight vertical lift of 23 feet of water.

Flows of Water

One *cubic foot per second* equals 450 gallons per minute or 0.646 million gallons per 24 hours.

One *cubic foot per second,* or 450 gallons per minute, will furnish *one acre-inch per hour;* that is, it will cover one acre to a depth of one inch in one hour.

Pump and Electric Motor Calculations

$$\textit{Theoretical Water Horsepower of a Pump} = \frac{\text{Gals. per Minute X Pressure at Pump in Ft.}}{3960}$$

$$\textit{Actual Horsepower Applied to Pump} = \frac{\text{Theoretical Horsepower}}{\text{Pump Efficiency}}$$

$$\textit{Kilowatt Input} = \frac{\text{Gallons per Minute X Pressure at Pump in Feet}}{5308 \text{ X Pump Efficiency X Motor Efficiency}}$$

One acre-inch of water lifted one foot requires approximately one-sixth kilowatt hours of electrical energy. An average pump and motor efficiency of 50 per cent is assumed.

One *horsepower*=746 watts.

One *kilowatt*=one and one-third horsepower.

One *kilowatt*=1000 watts.

Single-stage centrifugal pumps under ordinary conditions vary in efficiency from 50 to 80 per cent. These figures should be expressed as decimals from 0.50 to 0.80 when they are used in the foregoing formulas. For belt-driven pumps, add 5 to 10 per cent to the actual power requirements to provide for belt slippage.

APPENDIX C

PUMPING

A few of the general ideas about pumping are discussed in Chapter III.

The usual type of pumps and wells are shown on Figs. 2, 3, 4, 22, and 26; with the methods of computing the total *head* or *lift* against which the pump must operate explained on Fig. 2. The manner in which this head affects the pump capacity is shown on Fig. 26.

Example of a Portable Pumping Installation

Pumps are available from so many manufacturers, in so great a variety, and to fit so many different irrigation requirements as to preclude describing them here.

A typical example is shown in Fig. 26. On this figure are included the irrigation and pumping details of a rugged gasoline pumping unit and an inexpensive pipe and high-pressure sprinkler distribution system serving 25 acres, although it has capacity for a much larger acreage. It is completely portable.

Figure 26 shows only one of the seven portable self-priming pumps listed in the 1953 catalog of this single manufacturer for irrigating by sprinkler or surface methods. These seven range in capacity from 100 g.p.m. (gallons per minute) against a 320-foot head (or lift) to 4000 g.p.m. against a 46-foot head. Of course a wide range of choices to meet any requirements is available from other manufacturers as well.

It will be recalled that 450 g.p.m. is equal to one cubic foot per second and that this will cover an acre with an inch of water in one hour.

Cost of Pumping

Figure 27 shows the amount of fuel or the cost of electricity for pumping water to various heights sufficient to cover an acre to a depth of one inch, or what is known as an acre-inch of water. One acre-inch equals 3630 cubic feet or 27,154 gallons. It should be noted that power costs per acre-inch may be prohibitive for high lifts or heads.

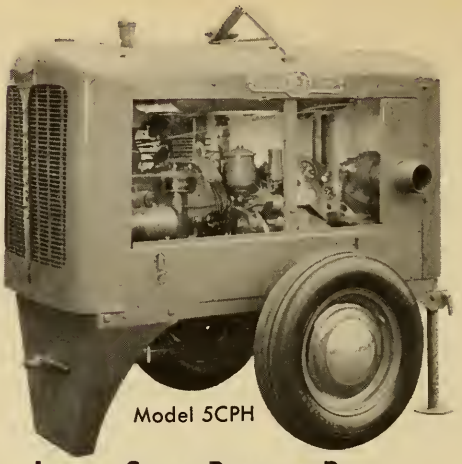
A modern combined electric motor and a 3- to 4-inch centrifugal pump for furnishing one cubic foot per second (450 gallons per minute) of water against low surface irrigation pumping

lifts (including the vertical lift, drawdown, and all friction losses) will cost several hundred dollars, excluding wiring, installation, and housing.

First cost, maintenance, and attendance are a minimum for the newer grease-lubricated, ball-bearing, built-in-electric-motor-type pumping unit; and it is apt to be the most reliable.

A gasoline motor and pump in a single unit such as Fig. 26 will require about the same total cost and also be reliable, and a Diesel unit will be more costly although it will be more economical in fuel consumption and repairs if used for heavy pumping over many seasons. The Diesel is too expensive in first cost for limited pumping and competent Diesel mechanics are seldom available. Where a tractor is available and the pumping is limited, pumps can be purchased that operate from the power take-off.

When pumping is used, it is especially desirable to diversify the crops so that the demands for irrigation will occur at different times. This permits the pumping plant, pipe, and equipment to be operated over more days and minimizes the initial cost per acre and the charge for interest, depreciation, taxes, and insurance.



Jaeger Super-Pressure Pump
(for 4" to 8" Pipe)

Model 5CPH for wide coverage with high pressure nozzles (saves piping), or for use where long supply lines or steep gradients require high pressures at the pump. Self-primes in few seconds by engine exhaust.
Big coverage with easily moved pipelines:

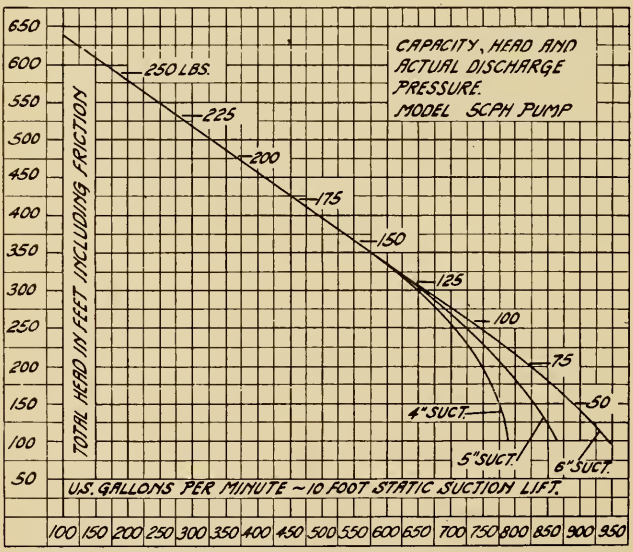
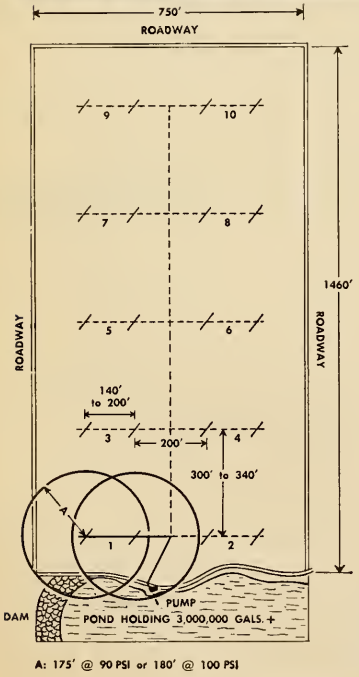


Fig. 26. Jaeger pump serving completely portable sprinkler systems, from their catalog. (Courtesy of The Jaeger Machine Co., Columbus, Ohio.)



Big coverage with easily moved pipelines:

Miller Farms, at Williamstown, New York, uses 1300 ft. of 6" main line with two 6" laterals each of which is 260 ft. long and carries two sprinklers with 1" main tips, spaced 140 to 200 ft. apart depending on width of fields served. While one lateral is working, the other is being moved to next setting—300 to 340 ft. back, depending on wind conditions. Model 5CPH pump, operating at 110 to 120 lbs. pressure, maintains 90 to 100 lbs. pressure at nozzles, each of which waters a 350 to 360 ft. circle. The area thus covered receives an average of 1.2 inches of water in 2 hours. The volume from each sprinkler can be regulated to apply uniform coverage. Complete cycle for the 750 x 1460 ft. field shown is 27 hours (three 9-hour days). This includes picking up and bringing in main line from another field and making 5 settings of the laterals. Fields up to 900 x 1500 ft. can be irrigated with 5 such settings. On narrower fields one sprinkler on each lateral and one 1¼" nozzle sprinkler on the main line are used to cover entire width of field at one time. System easily handles 50 acres a week. See explanatory diagram at left.

System consists of:
Model 5CPH Pump
1300' of 6" Main Line
520' of 6" Laterals (260' each)
45° Elbow (6")
90° Elbow (6")
4 Giant Sprinklers with 1" x 7/16" x 5/32" Nozzles
10 End Caps

Fig. 26 (Continued).

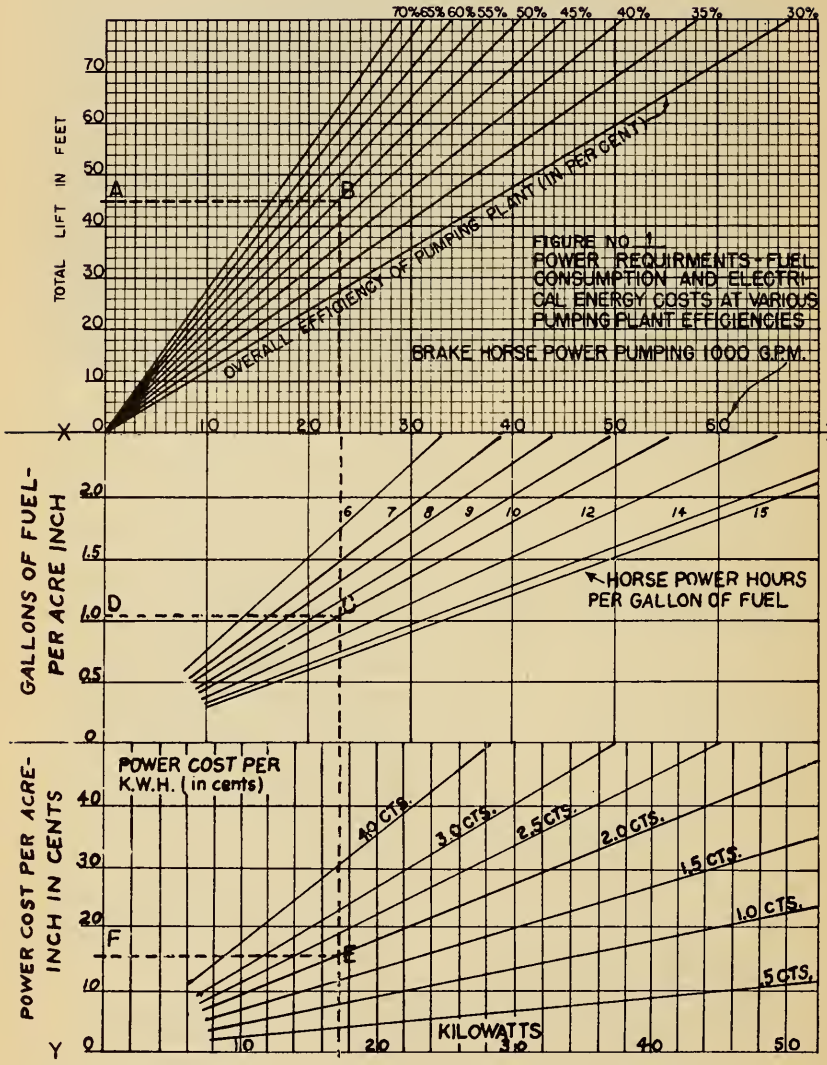


Fig. 27. Pumping costs. (Courtesy, U. S. Farm Security Administration.)

A POWER REQUIREMENT CHART FOR PUMPING

By means of this chart it is possible to determine power requirements, fuel consumption, and electrical energy costs at various pumping plant efficiencies and at various lifts.

At "A" at the upper left is the scale of lifts from 0 to 80 feet. The lift must include not only static head but friction and velocity heads as well.

At "B", upper center, overall plant efficiencies are represented. Overall efficiencies of small, irrigation pumping plants run from 40% to 60%.

On the line X-X ' is shown horse power values when pumping 1000 gallons per minute.

In the center of the chart, at "C", the fuel consumption of various types of engines is represented.

The approximate number of horse power hours developed per gallon of fuel for various types of engines is given below:

Type of Engine	Horse Power Hours Per Gallon of Fuel
Gasoline engines in poor repair	6 to 7
Gasoline engines in good repair	8 to 9-1/2
Engines using fuel, oil, semi-Diesel, etc.	9 to 11
High speed Diesel	11 to 14.5

At the lower part of the chart "E" is given the power cost in cents per acre-inch of water pumped at various rates in cents per kilowatt hour.

The line Y-Y' at the bottom of the chart represents the power required in kilowatts, when pumping 1000 gallons per minute.

Use of the Chart

The use of the chart is shown by the following example:
The lift of a given irrigation pump is 45 feet; the overall efficiency of the plant is estimated at 50%. What will be the horse power required to pump 1000 gallons per minute? How many gallons of fuel will be required to pump an acre-inch of water, using fuel oil in an engine other than Diesel? What would be the cost in cents per acre-inch, using electricity at 2¢ per kilowatt?

Starting at the upper left hand margin locate the lift, 45 feet at point "A". Follow to the right until the 50% efficiency line is intersected at point "B".

From the point "B" follow downward until the line X-X' is intersected. It will be noted that 23 horse power is required to pump 1000 gallons per minute. Continue downward until the line representing 10 horse power hours per gallon is intersected at "C". From the point "C" follow to the left to the point "D" which shows that 1.0 gallon of fuel will be required to pump an acre-inch of water.

If the cost in cents per acre-inch is required, with electrical energy costing 2¢ per kilowatt hour, follow downward from point "C" to point "E" on the diagonal line showing 2¢ cost. From point "E" follow to the left to point "F" which shows the cost of pumping one acre-inch of water under the given conditions to be 15 cents.

If the electrical load is required, follow downward from "E" to point "G" which shows a value of 17+.

If lifts other than those shown are to be used, certain allowances must be made. If values for a 100 foot lift are desired, those given for a 50 foot lift may be doubled, etc.

Fig. 27 (Continued).

APPENDIX D

SPRINKLER SYSTEMS

This appendix will give the irrigator an idea of how a system is designed but the actual design should be left to a local expert who should operate under the specifications of pages 84 through 87 if the irrigator expects a sure and guaranteed installation. It usually is very unsatisfactory for the irrigator himself to install the sprinkling system piecemeal.

The following material is quoted from Reference 28, *Irrigation Adviser's Guide* of the U. S. Bureau of Reclamation and was prepared for western irrigation conditions. However, it is impartial and authoritative and can be interpreted as necessary for eastern conditions. The reader is referred also to Chapter VI.

Types of Systems

Sprinkler systems are designated as stationary, semi-portable, and portable. Both revolving sprinkler and straight-line pipe systems may be either *high pressure* (30 pounds per square inch or more) or *low pressure* (20 pounds per square inch or less). Two general types of sprinkling devices are in use. In one, water is applied to the soil by means of perforated pipe. This pipe comes in sections 10 to 20 feet in length with *quick couplings* designed to make coupling or uncoupling easy and rapid and to be practically watertight at the pressure used. In a popular make the perforations are arranged in five lines lengthwise of the pipe. One line of holes spaced 2 or 3 feet apart runs along the center line at the top, and two parallel lines run at different distances from the top along the upper half of the pipe on each side. The pipe may be obtained in three styles which apply water at rates of 1 to 2 inches per hour. This type of sprinkler requires pressures from about 8 to 20 pounds per square inch, and will cover a strip 25 to 50 feet wide at each setting. The high rate of application of perforated pipe limits its use to soils with equally high infiltration capacities. The low pressure required and relatively low first cost are advantages of this system. Another make uses smaller pipe equipped with fixed nozzles spaced about three feet apart in a single line. This pipe is supported above the ground and must be oscillated either mechanically or manually. The lines are generally permanently located about 50 feet apart and operate at pressures of about 50 pounds per square inch.

In the second general type, the water is distributed by rotating sprinkler heads. These heads are mounted by means of riser pipes on light-weight, quick-coupling pipe. This pipe usually comes in 20-foot or 40-foot lengths. Risers may be less than 2 feet high for use on low-growing crops or to keep the water under the trees in an orchard, or as much as 30 feet high to throw the spray over the top of the trees. Risers and sprinkler heads are generally attached at intervals of 20 or 40 feet. These sprinklers operate on pressures from as low

as 15 to over 100 pounds per square inch. Sprinklers operating at the lower pressures and which throw the water out at a low angle to stay below most of the branches are sometimes used in orchards. Rotating sprinklers at the usual spacings will apply water at rates of from two-tenths to 3 inches per hour. Both galvanized steel and aluminum pipe are used for the portable lines, but the latter is more popular because of its light weight. There are many types of satisfactory quick-action couplings.

Generally a portable system is one in which the pump and lateral line are moved together; a semiportable system has a fixed pump and main line; a permanent system has pump, main and lateral lines in a fixed location. However, there are many combinations possible wherein an individual system may depart from this classification. In the semiportable system a main line fitted with outlets at appropriate spacings, usually 40, 60, 120, or 180 feet, is used. These outlets are fitted with self-closing valves. The portable lateral line is attached to the outlet by an elbow which is provided with a means of opening the valves. The main line may itself be either a quick-coupling line intended to be moved from time to time, or a permanent line which is often buried. When buried lines are used, provision should be made for draining to avoid freezing damage and to flush out silt and debris. Lines of permanent systems are usually buried. Where large sprinkler heads are used a valve is provided at each outlet and the heads moved from one outlet to the next. The high cost of this type of system often precludes its installation.

In operation, one or more portable sprinkler laterals are attached to the pump or to outlets in the main pipe line and laid out near one edge of the tract to be irrigated. After the strip, usually 40 or 60 feet wide, has been sufficiently wetted, the line is disconnected, moved over, and set up in the center of a new strip. One man can pick up a 40-foot section of the smaller sizes of aluminum pipe at the center, unlock it, carry it to the new position and lock it, all without going to the coupling. For intermediate sizes, one man can handle a 20-foot length in the same way. With the large sizes two men are required for 20-foot lengths. Sometimes it is feasible for three men to handle two 20-foot sections, or four men, 3 sections. The period of sprinkling may run from 1 to 24 hours, although the most common periods are 2 to 3 hours or 11 to 12 hours. In order to fit into the farm labor schedule, sprinkler systems are usually set up as *job* or *chore* types. With the first type, irrigation is a full-time job and each sprinkler line is moved every 2 or 3 hours, while with the second, the lines are moved as a chore once, twice, or occasionally three times in 24 hours.

To minimize the labor required in moving portable laterals, large sprinklers have been developed. These sprinkler heads have one to three nozzles, require pressures of around 100 pounds per square inch, discharge from 200 to 600 gallons per minute, and may cover an acre or more at a single setting. They are usually installed on risers attached to permanent pipe lines.

The wheel-move system, among many others, has also been de-

veloped as a labor saving device. Light and sturdy wheels are placed at 30 or 40-foot intervals on the lateral lines using the pipe as an axle. At moving time the line is disconnected, automatically drained, and rolled to a new location. This new development has not been proven under all conditions but has shown promise in many instances.

Design of Sprinkler Irrigation System. One of the prerequisites to a good system design is a map of the area to be served. This map, of any convenient scale, should show the farm unit boundaries, farm delivery point or source of water and the necessary elevations of the farm unit area. This map may be used to show the final layout of the system when the design has been completed. Many times soil and topographic maps of the area are available and may be referred to for valuable information.

Of the several factors which must be given careful consideration in the design of a sprinkler system usually one or more are fixed by existing conditions, and the others must be adjusted to fit into these fixed requirements. The following discussion is confined to the design of portable, revolving head sprinkler systems. This procedure is illustrated by the design of a system for the irregular shaped farm unit shown in Fig. 28.

Depth and Frequency of Application. The depth of water which will be needed to replace soil moisture at each irrigation and the frequency of application to be expected have been covered in Chapter VII.

When the area to be served by the sprinkler system is composed of two or more soil classes having significantly different values for moisture replacement, consideration should be given to the subdivision of the area on the basis of the amount of water to apply at each irrigation. When it is not possible to divide the field as to soils, the soil having the greatest water requirement will be the criteria of the design.

To determine the gross amount of water required for each irrigation, the efficiency of water application of the system should be considered. *Field Irrigation Efficiency* is defined as the percentage of the water delivered to the field that becomes available to the crops as soil moisture. Until more definite data are secured for specific areas, the following irrigation efficiencies for sprinklers should be used:*

(a) Use 70 per cent as a base figure for moderate climatic zones.

(b) Increase this to 80 per cent in coastal or fog belt areas.

(c) Decrease the base figure to 60 per cent for hot, dry climates.

(d) Decrease the base efficiency for (a), (b), or (c) above, for areas having more than 5 miles per hour average wind movement during peak use periods. Subtract 5 per cent for each additional 5 miles per hour.

(e) Decrease the base efficiency for operation on slopes over 12 per cent, 5 per cent for every 5 per cent increase in slope.

*Soil Conservation Service.

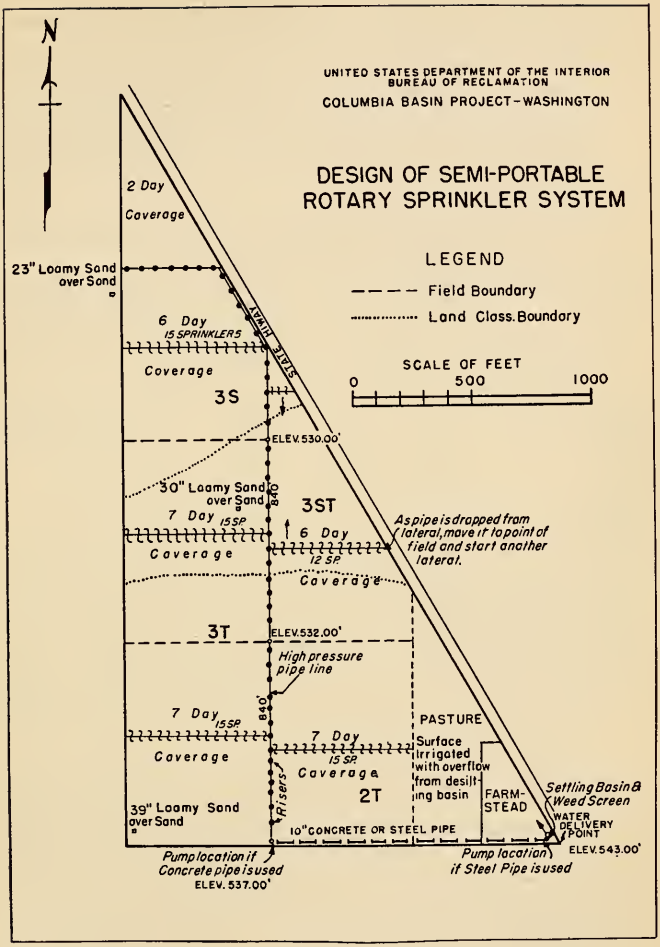


Fig. 28. Semiportable sprinkler irrigation system. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

(f) Decrease the base efficiency when water application rates are below the minimum rates recommended for each climatic zone.

The required frequency of application of irrigation water is governed by the quantity of available moisture stored in the root zone during an irrigation and the rate at which that water is tran-

spired by the crop and evaporated from the soil surface. It is essential that the system be designed to supply the required moisture for optimum crop growth during that portion of the season when the crop is transpiring at the maximum rate, allowing for losses in efficiency of water application. This is commonly referred to as the peak-use rate. Approximate peak-use rates may often be obtained locally from State Experiment Stations and Department of Agriculture research agencies. Where these values cannot be obtained locally, approximate values for climatic zones in the Western States given in Table VII may be used.

TABLE VII
PEAK MOISTURE USE FOR COMMON IRRIGATED CROPS AND OPTIMUM YIELDS[1]

Crop	Cool climate		Moderate climate		Hot climate	
	In./day[2]	G.p.m./ac.[3]	In./day	G.p.m./ac.	In./day	G.p.m./ac.
Alfalfa	0.15	2.8	0.20	3.8	0.25–0.30	4.7–5.7
Pasture	.12	2.3	.16	3.0	.20– .25	3.8–4.7
Grain	.15	2.8	.20	3.8	.22	4.2
Potatoes	.10	1.9	.12	2.3	.14	2.6
Beets	.12	2.3	.15	2.8	.20	3.8
Deciduous orchards	.15	2.8	.20	3.8	.25	4.7
Orchards with cover	.20	3.8	.25	4.7	.30	5.7

[1]Soil Conservation Service.
[2]Acre-inches per acre per day.
[3]Continuous flow required per acre at 100 per cent irrigation efficiency. Divide this value by estimated irrigation efficiency.

Often other factors, such as harvesting operations are involved which make it necessary to cover the design area in a period less than irrigation frequency period.

In determining the irrigation requirement for a given area, a future crop pattern must be assumed or predetermined. The crop which will be used in general farming with the highest water use should be used as the criterion for design. Generally speaking, this crop is alfalfa in most areas. In the design of a sprinkler system, it is necessary in most cases to assume that at some time the entire area will be devoted to a crop which is a heavy user of water, such as alfalfa. In order for the settler to utilize the system to the best advantage, he should be alerted to laying out his fields and cropping rotation to permit good lateral management practices. For instance when the soil and consumptive use of the crop being grown require an application every 9 days, the system should be designed so that the laterals can cover the fields in a 7-day period. This will permit a 2-day leeway in the schedule for other activities and an opportunity to catch up if the irrigation schedule should become delayed.

Capacity of System. The capacity of a system designed for a particular area may be determined when the acreage to be irrigated, the total amount of water to be applied, and the net operating time

allowed to apply the required water is known. The capacity of the system in gallons per minute can be computed from the formula $Q=453\frac{A\ d}{F\ H}$ where: Q is the discharge in gallons per minute; A is the area to be served in acres; d is the gross depth of water application in acre-inches per acre; F is the number of days permitted for the operation; and H is the average number of hours of operation per day.

Application Rate. The rate at which water is applied to the soil is governed somewhat by pressure but largely by the nozzle size and spacing of the sprinkler head. This application rate should never exceed the rate at which the water is absorbed by the soil during an irrigation period. This will eliminate runoff and the ponding of water on the soil surface. In order to determine this maximum application rate, it is necessary to have some information on the infiltration capacity of the soil. Often local representatives of the State Experiment Stations, Soil Conservation Service, or the Bureau of Reclamation will have data of this type available. In the absence of data for the specific soil to be irrigated, the following rates may be used:

Soil type:	Infiltration capacity, inches per hour
Sand	2
Sandy loam	1
Loam	0.5
Silt and clay loam	0.2

Where there is assurance that a good ground cover can be established without erosion, the maximum application rate may be used. At the other extreme, exceedingly low application rates are not satisfactory for efficient irrigation under adverse climatic conditions.

A rate of application will be selected which will require a time of setting which will most nearly fit the farm operation schedule on that particular farm. For the average farm, using the chore-type system, it is usually desirable to have a time of setting intervals, which will give one, two, or three changes per day.

Line and Lateral Spacing. The present tendency with rotary sprinklers is to use a rectangular pattern and to provide an overlap of at least 100 per cent in one direction. The maximum spacing in the other direction should not exceed 70 per cent of the diameter covered by the sprinkler. In the Pacific Northwest, a spacing of 40 feet between sprinklers on the portable line and 60 feet between settings of the lines is almost universal. In other sections, sprinklers are often spaced 20 feet on the lines. This close spacing would not be necessary on the basis of the distribution of good sprinklers in calm air, but has been found desirable in actual practice in windy regions.

Number and Size of Sprinklers. The rate of application desired will generally determine the size of the sprinklers. The number of sprinklers necessary may be determined by dividing the capacity of the system (gallons per minute) which has been set for peak season needs, by the desired rate of application of sprinklers (g. p. m.). The number so determined provides an important guide in the arriving at the required layout of main line and laterals even though it will usually need to be changed to fit the final layout selected.

Layout of Main Line and Laterals. . . . . In determining the location of the pump, the location and length of the main line must also be considered. Considerable latitude of judgment may be exercised in the layout; however, in order to have an efficient layout, there are several general rules which should be followed whenever possible.

The main line should be laid on the predominant land slopes. This allows the laterals to be laid across the slope or as nearly on the level as possible to minimize pressure variation. Changes in pipe size on the main line sometimes may be made for pressure control. In general, main line pipe sizes should be selected on the basis of favorable balance between amortized cost of pipe compared with annual power costs. A number of shortcut methods have been developed for determining the economic size of pipe. Essentially, it requires a comparison of the difference in the annual cost (interest and depreciation) of two different sizes of pipe being considered with the annual cost of energy for overcoming the excess friction in the smaller pipe. The latter cost is a function of the friction, the rate of flow through the pipe, the number of hours of flow per year, the efficiency of the pumping plant and the cost of energy. The annual cost of energy can be determined by the use of the power cost graph shown in Fig. 29.

Whenever possible, the lateral layout should facilitate the rotation of multiple laterals to avoid long hauls of laterals back to the starting position. Where laterals are laid down-slope, it may be necessary to depend upon manually operated valves at points on the line to control pressures.

The size of the laterals is determined in much the same manner as the main line but limiting the total variation in pressure along the lateral to 20 per cent or less. Table VIII may be used to determine the proper lateral sizes.

TABLE VIII

FACTORS FOR CALCULATING FRICTION IN LATERALS*

Flow-gallons per minute	Size of pipe				
	2 inch	3 inch	4 inch	5 inch	6 inch
40	88	11	2		
60	256	31	7	2	
80	560	69	16	5	1
100	1,029	127	30	9	3
120		211	49	16	5
140		324	75	24	9
160		471	110	36	13
180		655	153	50	19
200		879	206	67	26
250			388	126	49
300			653	212	84
350			1,014	329	131
400				480	193
450				672	270
500				962	365
550				1,260	480
600				1,618	617
650				2,030	777

*Adapted from Irrigation Equipment Co.

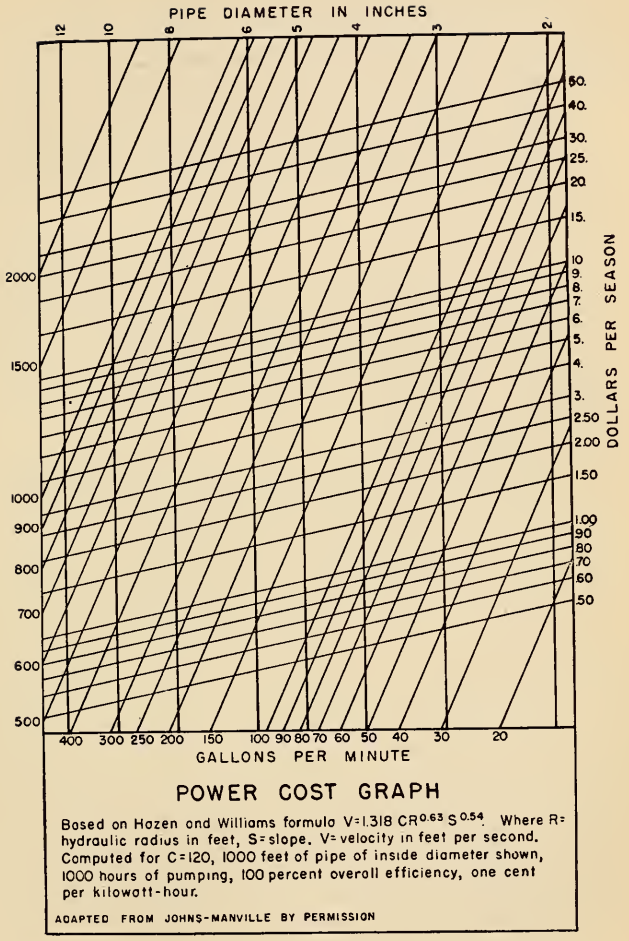


Fig. 29. Power cost graph. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

The left-hand column of this table shows the quantity of water entering the lateral. In the body of the table, factors are given for different sizes of pipes corresponding to the quantities in the left-hand column. These factors, when divided by the number of gallons per

minute discharged per 100 feet of lateral, give the friction loss in head throughout the length of the lateral.

The layout of the laterals and main lines for an area must provide for the simultaneous operation of the number of sprinklers which, when operating at the discharge requirement to meet the application rate, will utilize the required system capacity. It should also provide practical lateral lengths and sizes in which pressure variation will not exceed 20 per cent. The number of settings for each operating lateral cannot exceed the number of settings per day times the maximum number of days allowed for peak use irrigation period. After the lay-out of the main lines and laterals has been completed, it is generally necessary to make some adjustment in one or more of the other design characteristics.

Pump and Motor Capacities. It is very important that the proper pump and motor be selected to meet all operating conditions. In order to determine the power requirement, it is necessary to compute the total pumping head. This is found by adding the pressure losses in the system and the pressure requirement at the most distant sprinkler, taking into consideration any effective difference in ground elevation. With the total pumping head known, the power required is computed by the following formula:

$HP=\frac{H\,Q}{3{,}960\,E}$. Where HP is the horsepower required, H is the total pumping head in feet, Q is the discharge in gallons per minute, and E is the over-all efficiency expressed as a decimal fraction. A pump and motor to meet these requirements may be selected from pump catalogs.

After the complete system has been designed, a map showing the entire layout should be prepared. This layout may often be placed on the map prepared prior to the design of the system. The sprinkler operator should also be informed of the entire design plan and operating principles in order that he may obtain the designed performance from the system. . . . .

Weed Screen and Desilting Basin Requirements.* Most projects are exposed to some soil erosion by wind or water. This is particularly true when projects are being settled. Consequently, considerable sand and soil drifts into canals and laterals. This in turn, is frequently conveyed by the water to the farm unit. Sand and silt have an adverse effect on sprinkler equipment. It results in undue wear of the impeller blades of pumps and the eroding of pipe and sprinkler heads. In extreme cases, it has been necessary to replace sprinkler heads that have been in operation less than one season. In some instances, silt high in colloid materials has caused sprinklers to stick. This freezes them in one position. Weeds, seeds, and moss are also conveyed to sprinkler systems by the water and should be eliminated before they pass into sprinkler lines. It is considered almost imperative for successful sprinkler operations that a combination weed screen and desilting basin be constructed between the ordinary lateral turnout [or surface water supply] and the pump intake.

Fig. 30 is an effective combination weed screen and desilting

*Author's Note—Not often needed in eastern supplemental irrigation.

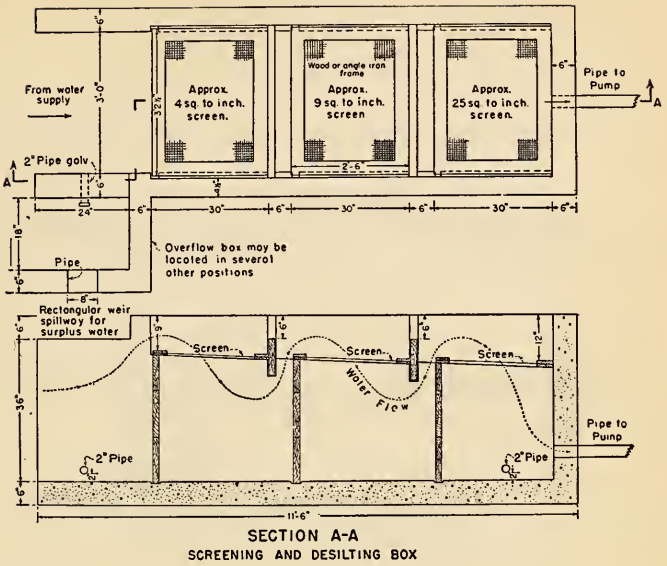


Fig. 30. Desilting basin and screen for sprinkler system. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

basin. It has been used successfully on a number of projects. This basin is designed for approximately 450 gallons per minute and should be increased in size in accordance with the capacity of the sprinkler system. In some instances, sprinkler users have diverted the water from the turnout into a small pond excavated for use as a desilting basin. However, weed screens should be provided to keep trash from entering the system. Moss is one of the most difficult things to eliminate from the screens as they become plugged and require considerable attention to keep them functioning properly. Some operators connect a ¾ inch garden hose to a tap installed on the discharge side of the pump. The hose is then placed under the screen to permit the water to run through the screen. This cleans an area sufficient in size to permit flow to the pump.

Fig. 31 shows a jet sand pump which reduces the labor of removing silt and sand from the pump. It derives water pressure from the discharge side of the pump.

Wind. Wind is an important factor in determining the efficiency of a sprinkler irrigation system as the distribution pattern is greatly influenced by it. Water losses occurring between the sprinkler and the ground surface increase as the wind velocities increase. Water loss,

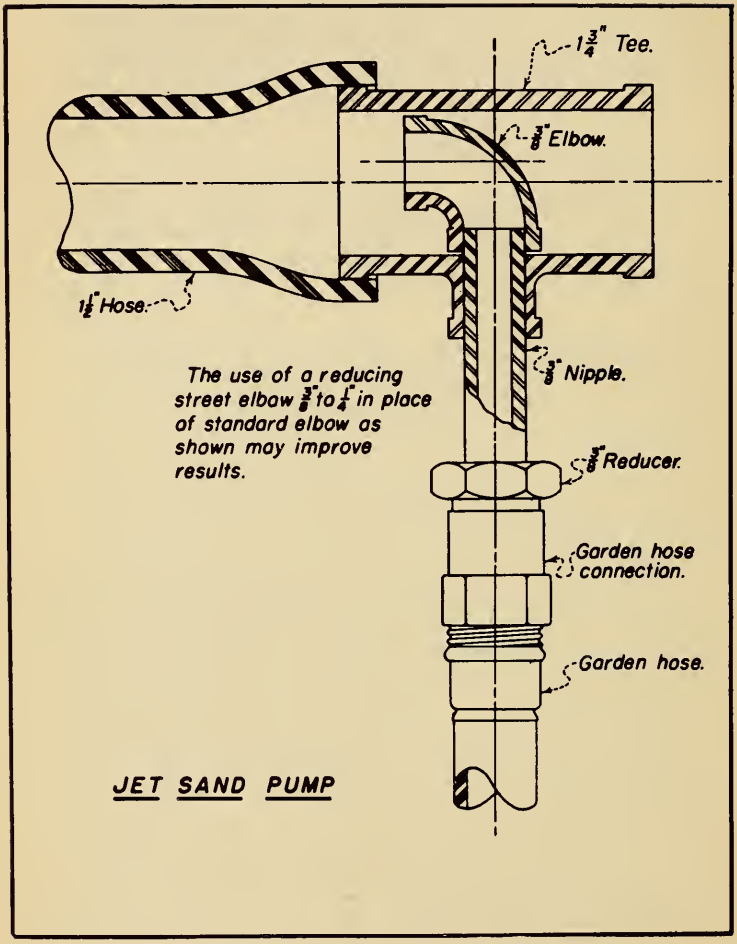

1¾" Tee.
⅜" Elbow.
1½" Hose.
The use of a reducing street elbow ⅜" to ¼" in place of standard elbow as shown may improve results.
⅜" Nipple.
⅜" Reducer.
Garden hose connection.
Garden hose.
JET SAND PUMP

Fig. 31. Jet pump for cleaning desilting basins. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

through deep percolation, also increases as the wind causes irregular distribution with excess water at some points and deficiencies at others. The uneven distribution can be corrected somewhat by changing the position of the lateral at alternate applications. The most desirable method to use on the conventional 60- by 40-foot spacing is to employ a 30-foot section of pipe with a 90° elbow and locate the lateral on a 30-foot offset from the previous set. The 30-foot location immediately between the lateral valves is the best location to correct the condition. Whenever the unit boundaries make it economically possible, the system should be laid out to permit the laterals to be placed at right angles to the prevailing wind. This practice aids in compensating for wind influences on the pattern but is not nearly sufficient to fully compensate for the poor distribution resulting from the wind.

Design of Semiportable Sprinkler System. The irregular farm unit containing 57 acres of land shown in Fig. 28 is used to illustrate the actual design of a sprinkler system. This unit receives water from a turnout located at the high point of the farm unit. A portable, revolving-type sprinkler operated as a chore-type system will be used. The soil to be irrigated is predominantly loamy sand to a depth of approximately 2.5 feet, underlain by sand. . . . The available moisture for plant growth in the soil of this texture is between 2 and 3 inches. The capacity is assumed to be 2.5 inches for the root zone of medium depth. Since it is expected that, at some times, the entire farm will be in alfalfa, the system will be designed to meet the peak water requirement for alfalfa, which is estimated at about 0.28 inch of water per day. See Table VII. In this case, 9 days would be required to use the available moisture from the effective root zone. To provide a desirable safety factor, a frequency of 7 days will be used instead of the calculated 9-day frequency. To make allowance for losses incurred during application we assume a field efficiency of 65 per cent. The total requirement for each irrigation would then be 3.85 inches. Assuming that one hour out of each twelve is allowed for moving the lateral, the sprinklers will operate 11 hours at each set or 22 hours per day. The capacity of the system determined by the formula $Q=453\frac{A\ d}{F\ H}$ will be 646 gallons per minute.

The rate of application is found by dividing the desired depth of application, 3.85, by the duration of each set, 11 hours. The result is 0.35 inch per hour. This rate is well below the infiltration capacity for a soil of this type. This application rate may be converted into the discharge of sprinklers by the formula $GPM=\frac{P\ A}{96.3}$ in which the GPM is the discharge of each sprinkler in gallons per minute, P is the rate of application, A is the area in square feet commanded by each sprinkler, i.e., the product of the spacing of the sprinklers on the laterals by the distance the laterals are moved each time. The wind

velocity is assumed to be not more than 5 miles per hour which would permit operating the 60-foot lateral spacing in view of the recommendation that the spacing be held to 70 per cent of the wetted diameter.

Since the 40 by 60 sprinkler and lateral spacing are used, we may substitute and obtain a sprinkler discharge of 8.72 gallons per minute. Sprinkler manufacturer's charts recommend that nozzle sizes be 3/16 by 1/8 inch and be operated at approximately 37 pounds pressure to supply the required amount of water.

Concrete or steel pipe may be used to convey the water from the turnout to the pumping plant which has been located in a more central location than the turnout. The 6 foot drop in elevation between the turnout and the pumping plant will compensate for the friction loss in a 10 inch pipe carrying 646 gallons per minute.

Tentative lateral layouts have been made so that the laterals can best serve the fields. The laterals carry a sufficient number of sprinklers to conduct the irrigation on a 40- by 60-foot spacing. Seventy-five sprinklers will be required when all laterals are being employed. Each irrigation will require 7 days, operating 22 hours per day, totaling 154 hours. Twelve irrigations will be needed for the season, totaling 1,848 hours.

A main line pipe, sufficient in size to carry 646 gallons per minute, will be required for a distance of 840 feet to the north end of the first field. From this point on, a smaller main line which will carry 384 gallons per minute may be used. The size of these pipes must then be fixed. Using the power cost graph, Fig. 29, the economical size of pipe may be determined. The power rates for the area average 1 cent per kilowatt hour. The overall efficiency of pump and motor is 65 per cent, the friction coefficient of 120 is accepted, and the seasonal pumping has been computed to be 1,848 hours. The factor for converting the cost taken from Fig. 29 to the conditions of the designed problem is computed as follows:

$\text{Factor} = \frac{1,848}{1,000} \times \frac{100}{65} = 2.84$. The application of this factor to the power cost from the figure gives the annual power cost per 1,000 feet of pipe shown in Table IX below.

Bituminous-coated steel pressure pipe has a life expectancy of 30 years. The annual depreciation for this class of pipe is 3.33 per cent. The interest rate is assumed at 5 per cent. The combined depreciation rate is 8.33 per cent. Application of this rate to the installed costs of 1,000 feet of pipe of different sizes will give the annual fixed cost shown in the following Table IX:

TABLE IX

ECONOMIC SIZE OF MAINS

No. 1 section of main line—capacity 646 gallons per minute—length 840 feet.

Pipe size	Annual cost per 1,000 feet of pipe		
	Interest and depreciation	Seasonal power cost	Total annual cost
10	$2,150 x 8.33 = $179	$ 3.80 x 2.84 = $ 11	$190
8	1,570 x 8.33 = 131	12.00 x 2.84 = 34	165
6	1,110 x 8.33 = 92	45.00 x 2.84 = 128	220
	Use 8-inch pipe		

No. 2 section of main line—capacity 646–262 = 384 gallons per minute—length 840 feet.

8	$1,570 x 8.33 = $131	$ 2.50 x 2.84 = $ 7	$138
6	1,110 x 8.33 = 92	11.00 x 2.84 = 31	123
5	910 x 8.33 = 76	27.00 x 2.84 = 77	153
	Use 6-inch pipe		

No. 3 section of main line—capacity 384–260 = 124 gallons per minute—length 780 feet

4	$ 710 x 8.33 = $59	$ 3 x 2.84 = $ 8	$67
3	510 x 8.33 = 42	13 x 2.84 = 37	79
	Use 4-inch pipe		

For convenience in operation the five laterals used on the unit will all be the same size. The desirable diameter of the lateral is determined through the use of Table VIII. The entire lateral capacity amounts to 128 gallons per minute. Each 100-foot section supplies 21.3 gallons per minute. Interpolating 128 on the chart indicates the factor to be 256 for a 3-inch lateral. When divided by 21.3, the outflow per 100 feet, a head loss in the lateral of 12.0 feet is obtained. A pressure of 37 pounds is required at the end sprinkler. The pressure variation in a single lateral should not vary more than 20 per cent in order that the rate of application or discharge of sprinkler will not vary more than 10 per cent. The head loss of 12 feet or 5.2 pounds is within the allowable 20 per cent so 3-inch lateral lines are recommended.

The friction losses, estimated from the Williams and Hazen formula with C=120, and the pressures in the system are:

	Feet
No. 1 section of main, 840 feet 8 inches	8.0
No. 2 section of main, 840 feet 6 inches	11.8
No. 3 section of main, 780 feet 4 inches	9.8
Fittings (Allow 10 per cent of above)	3.0
Laterals	12.0
Risers	1.0
Pressure at most distant sprinkler	85.8
	131.4
Effective ground elevation difference	−7.0
Total pumping head	124.4

$$HP = \frac{124.4 \times 646}{3{,}960 \times 0.70} = 29 \text{ HP.}$$

A 30 horsepower electric motor will be used.

APPENDIX E

SURFACE LEVELING SYSTEMS

The general nature of leveling land for surface irrigation is treated in Chapter V. Appendix E is quoted from the U. S. Bureau of Reclamation's *Irrigation Adviser's Guide* (Reference 28). It applies more directly to western conditions where several times more irrigation water is applied than in the East, and consequently more leveling is justified. However, the same principles apply in the East but to a slighter degree.

Correlation of Land Leveling and Soils. It is doubtful that much land is properly developed today without a prior land classification. The recent classifications are usually in sufficient detail to give much information relative to the depth and character of the soil profile, soil texture and structure, and the salinity or alkalinity of the surface soil and subsoil. The adviser must know the depth and quality of the soil when designing a leveling plan since permanent damage can be done to the soil by making excessive cuts in shallow or hardpan areas. The allowable limits of excavation should be fixed from the information contained on the land classification map. Damage can be done to some soils by working them with leveling equipment when the moisture content approaches the field capacity. It should be remembered that if the ground is too moist for farming operations, it is equally so for leveling operations.

Correlation of Land Leveling and Irrigation Methods. The term *wild flooding* is used to designate all methods by which water is spread over the surface of the land without guiding ridges. Often, on stream bottoms of mountain valleys, the streams are dammed and the water is forced to flow out over the adjoining land. This method is not prevalent on Bureau projects. On rough or steep land and on shallow soils, irrigation is often carried on by wild flooding from contour or ridge ditches. Generally, under these conditions, land leveling is not feasible. Occasionally, minor high and low areas are cut or filled to correspond to the surrounding land. Work with a survey instrument is seldom necessary as the steep slopes neutralize most small irregularities and the large ones are easily seen. Land being irrigated by this method should be floated before each planting to remove the irregularities caused by small rivulets that frequently are formed by water flowing down the steep slopes. Often, then this policy is not followed, the rivulets cut to depths that impair future irrigation. Many farmers find that seeding on the contour is not only a good soil-saving practice but also an aid in the distribution of the water. The small furrows left by the drill tend to check the velocity of the water and spread it more evenly over the surface.

Leveling land for water distribution by the *furrow* or *corrugation* method has fewer limitations than leveling for borders. This is largely because the shallow furrows or corrugations guide the water down the slope. Since furrows and corrugations will do this on land with con-

siderable cross slope, more tolerance is allowable in adjusting the cross gradient to fit the topography. However, when laying grades, one should never permit the cross slope to exceed one-half the longitudinal slope, except in extremely favorable soil conditions which may permit a maximum of cross slope equal to the longitudinal slope. Spot leveling is frequently adaptable to this method of irrigation.

Less leveling is required for the *basin* method of irrigation than for other types. The procedure for general leveling should be followed. Basins can be used in several forms. On very flat land, level rectangular basins are formed on each side of feed ditches so located as to take advantage of any fall there may be. On land with slightly more slope, level basins may be built with the ridges following contour lines and the ditch running down the slope. In this case, the basins are generally irregular in shape and on tight soils may be rather long and have a slight longitudinal slope. The basin method merges into the border method at this point. Considerable departure from the longitudinal grade can be tolerated where the basins are located approximately along the contour. Earth can be moved down the slope by use of a power patrol, blade grader, or a terracing machine to form such contour basins. The feasibility of using this equipment is determined by the width of the basin desired. A windrow of earth, cut from the high side of the basin, can be moved three times the effective working width of the blade before the cost of a pick-up scraper is justified. Long strips can be quickly checked into basins of desired length through the use of a ridger. Basins are sometimes leveled separately. The leveling of individual basins can best be done by the use of small wheel or drag scrapers.

In designing for *border* irrigation, it is desirable, where possible, to run the borders directly down the slope. Cross and longitudinal slopes, soil characteristics, and the size of the irrigation stream available determine the number of borders to be used in preparing a field for the border method of irrigation. No cross slope is permissible in the finished strip. Cross slopes cause water to accumulate on one side of the strip, resulting in a poorly irrigated crop and increased cost of water application. The longitudinal slope, which is the slope in the direction in which the field is to be irrigated, generally should not exceed 2 per cent. Under certain conditions even this slope is excessive. Often, when slopes exceed 0.3 foot per 100 feet, it is necessary to use corrugations within the border, especially in starting new seedings. A uniform longitudinal slope is desirable but is not necessary. Departures of 0.1 foot from grade in the longitudinal direction are permissible when slopes are 0.2 foot per 100 feet or over. Greater departures are allowable on more sloping ground.

Where possible, it is advisable to create a flat zone adjacent to the head ditch and extending outward 20 to 30 feet. This will spread the water across the upper portion of the border which in turn will aid in keeping it spread for the remaining length of the run. Where borders are to be made on steep ground it is desirable to locate an additional stake line on the edge of the above-described flat zone. This

will aid in the recognition of this zone at the time grades are being considered.

Frequently, the ridges are made with implements that borrow the earth from strips within a few feet on each side of the ridge. A small depression along each side of the ridge usually results when this method is used. It is desirable to move earth into the depression to prevent the water from forming a stream along the ridge. Floating within the border removes small irregularities in the grade and also aids in eliminating minor cross slopes that may have been overlooked during the heavy equipment operations.

The installation of *sprinkler* irrigation may be economically justified by the fact that little or no leveling is required on land upon which sprinklers are used. The ground should always be floated before planting. This will aid in eliminating small indentions in which water may collect. It is seldom necessary to enter into an intensive leveling program, although some farmers do recommend considerable preparatory leveling.

Topographic Surveys. On land with slopes of over 5 per cent, detailed topographic mapping generally is not justified.

It is often said that a good topographic map is the basis of planning an efficient irrigation farm. The more the adviser works with the farmer and encounters problems in leveling and water distribution, the more he becomes conscious of the truthfulness of this statement. Frequently, the source of water supply, such as a pump or turnout, has been improperly located because no adequate topographic map was available. Land has been leveled and large quantities of earth moved unnecessarily because a topographic survey was thought unnecessary. Farm distribution systems have been installed and proved faulty for the same reason. Errors of this nature have resulted in additional expense which, in most cases, greatly exceeded the cost of a survey.

A good topographic map is not expensive. Contract prices range from 75 cents to $1.25 per acre. The cost usually depends upon the number of irregularities occurring in the area to be mapped. The refinement of topographic mapping is expressed in contour intervals. The 1-foot interval is generally accepted as most practical for detailed design of distribution systems and for planning land leveling on the farm. On flat lands, a 6-inch contour interval is sometimes desirable. The elevation of enough points to indicate any depressions, knolls, abrupt changes in slope, or saddles that may exist within the contour interval should be shown on the map. Recorded elevations other than on the contour will aid in interpolation of more frequent contours, if desired. The contour interval selected as most practical for detailed design of the distribution system and for planning land leveling on the farm varies directly with the regularity of topographic features and slope. A good general rule to follow in determining the contour interval is that the satisfactory contour interval in feet is equal to the predominant grade per cent in the area to be surveyed.

The size of the area considered often influences the scale to be

used in preparing the topographic map. A map prepared on the scale of 1 inch equals 100 feet is desirable for farms ranging up to 80 acres. The scale of 1 inch equals 200 feet is preferable for areas exceeding 80 acres. The scale of 1 inch equals 400 feet can be used but it is not as satisfactory for design work as the scale of 1 inch equals 200 feet.

Several methods can be used in making a topographic map. For large areas, the plane table and alidade method is more efficient and the finished product will cost as little as one made by any other method. Excellent topographic maps can be made by using the physical features shown on aerial photographs, as an added horizontal control. This is best done by placing the aerial photograph on the plane table in the same manner as the regular paper, but with a transparent overlay. The recording of the topography is then done in the conventional manner. Features obtained from the aerial photograph give added detail and control to the completed map.

The size of the crew for plane table mapping may vary from an instrumentman and a rodman to an instrumentman, recorder, and two or three rodmen. This, again, is dependent on the size of the area to be mapped.

Much topographic mapping has been done by the use of the transit. The transit is used in reading the level rod as well as stadia distances and horizontal and vertical angles, all of which are recorded in a notebook according to standard methods. This process usually requires as much time in the field as does the plane table survey. Its chief disadvantage lies in the fact that a great deal of time is required to transpose the field notes into a topographic map suitable for design work. Also, the draftsman does not have the opportunity to see the land while drawing contours or to check doubtful points. A survey crew taking transit topography may vary in numbers as may the plane table crew. Details of the methods of preparing topographic maps can be found in any good textbook on surveying.

Leveling Plan. After the topographic map has been completed, the leveling plan can be studied. It is possible that the detail map will bring out features not evident when the general farm and irrigation plans were made and that minor adjustments in these plans will be necessary. When these have been made, it will be possible to determine the best method of irrigating each field. Wherever the land is suitable, it is believed that the ultimate objective of a leveling program should be a border or flat basin system for close-growing crops and furrows for cultivated crops.

Farm units on legal subdivisions or rectangular fields often present a problem in choosing the direction of furrows or borders. In order to avoid point rows and uneven lengths of runs, it is desirable to make the direction of flow parallel to one or the other side of the field. Doing so may involve heavy leveling to avoid cross slope on borders, and this fact must be considered in determining the direction of irrigation and fixing the leveling plan. All of the land suitable for row crops probably will be used in some years of rotation plan for crops that are irrigated by border flooding or by corrugations. Fur-

rows are made parallel to border ridges and will not influence the leveling plan. For row crops such as corn or potatoes, which can be irrigated by deep furrows, the so-called contour method of irrigation may be used. . . . . .

Where borders are laid out in a direction other than straight down the steepest slope, it is necessary to move earth from the high to the low side of each strip and to form steps at each border. The resulting field may be difficult to work because equipment cannot cross the borders. Also, if the soil is shallow, the depth of cut required for this purpose may be prohibitive. Nevertheless, on the slight slopes where borders are suitable, it is usually possible to make them conform to property or field boundaries.

The decision as to methods and direction of irrigation will be greatly influenced by the quantity and cost of leveling required, as these are indicated by the study of the topographic map. The topography will reveal areas where leveling is required, the direction in which the earth is to be moved, and the most desirable locations for ditches. Earth quantities can also be determined quite accurately through the use of accurate topography.

Staking for Leveling. Unless leveling is required on only a few spots scattered over the field, or the cross slope to be taken out of borders is so great as to preclude the plan, the entire field should be staked and leveled as a unit. This does not mean that the field should be reduced to a single plane surface but that the construction of border ridges or ditches should not be undertaken until the over-all leveling of the field has been completed. After this has been done, the ditches and border ridges can be staked and constructed.

Staking the field for leveling can be started after clearing has been completed and the leveling plan has been determined. Examination of the topographic map will show in which direction earth must be moved to effect the desired results with the least labor and a balance of cutting and filling. Staking and checking will be somewhat more readily carried out if the movement is either in the direction of flow or at right angles to this direction.

The following discussion on laying out the leveling plan applies to an analysis of the particular unit illustrated in Fig. 32. In analyzing other units the same principles will apply but will differ in details since each unit is an individual problem. In examining the topography of this unit, it is apparent that the fields can be most economically leveled by moving the earth approximately parallel to the contours. The balance between cut and fill can be more easily accomplished in this manner. The profiles should be located in the direction in which earth is to be moved. The direction of the irrigation run would then be at right angles to the direction in which the profiles are located. The irrigation run is called the longitudinal direction of the field. The first step in staking is to locate the boundaries of the fields to be leveled. These are usually established on the topographic map. A uniform procedure for the staking of profiles and recording profile elevations should be established. A desirable method is the use of

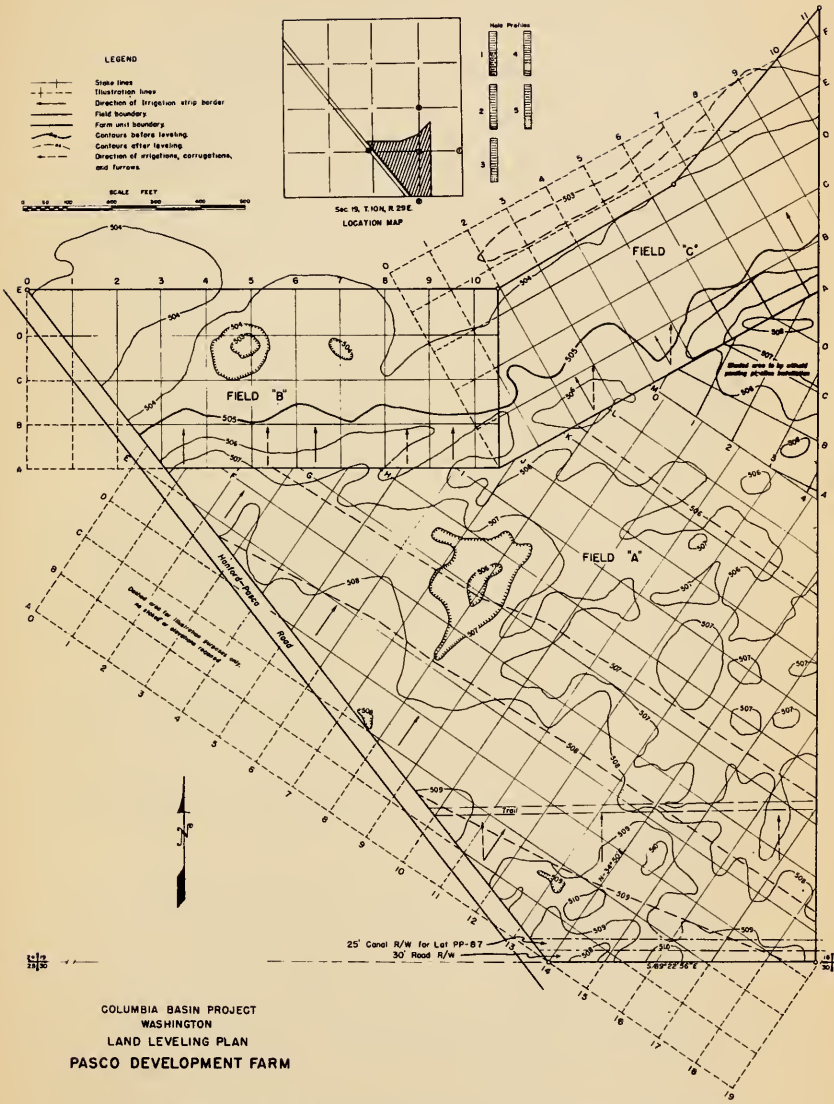


Fig. 32. Land leveling plan. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

letters for identifying the successive stakes in a longitudinal line and numbers for those in the transverse direction. The A line would then be at the upper end of the irrigation run and the 0 (zero) line would be at the extreme left side of the field. Where extensive leveling operations have been conducted, it has been found practical to place profile lines 100 feet apart. Often it is desirable to record the bearing of one line in each field on the topographic map. This bearing will aid field parties in establishing the lines on the ground.

Either full-length or half-length building laths make ideal stakes for land leveling. Two chainmen and an instrumentman usually constitute a well-balanced crew for staking profiles. In Fig. 32, the coordinate line A has but one station, this being A-14. The transit may be placed over this point and a longitudinal base line started at the bearing N. 34°50′ E. as fixed in study of the map. The next station would be 100 feet distant and identified as B-14, the following C-14, etc., until the extreme end of the run has been reached just beyond K-14. Should it be desired, each of the points established on the longitudinal line could be used as a transit point and profiles run at right angles in both directions. Work often can be expedited by establishing two transverse and two longitudinal lines by transit and then lining in the other stations by eye. Stakes should be placed at all stations and at all breaks in the slope occurring in the surface of the ground between the stations.

In all cases where accurate leveling is necessary or the soil is loose and easily disturbed a small stake (1x1x8 inches) called a hub should be driven with its top flush with the ground surface at each point. The lath is then set at a definite and uniform distance and direction from the hub as an aid in locating the latter. The lath is used also for markings as discussed in the following paragraph. Rod readings are taken on the hubs.

The method of picking and plotting breaks can best be illustrated on the H profile line of Fig. 33. The profile commences at station H-4 + 60. A depression is encountered at station H-4 + 85 and a stake or a lath is driven to show this break. The next point is at station H-5. Stakes are placed at each 100-foot station until a break is encountered at H-7 + 20. A stake is placed at this point and the work is continued to the edge of the field at H-16 + 50. All profile lines are staked in this manner.

Upon completion of the staking, elevations in the field can be obtained. Sea-level datum should be used when available. Rod readings are taken at the ground line or on the hub at each stake. Some engineers will prefer to keep notes in the customary manner in bound books. A method in which loose-leaf sheets (8½x11 inches, 11 x 17, or larger) of cross-section paper are used in the field for taking notes and plotting contour lines is sometimes followed. The use of loose-leaf sheets is believed to be more efficient, as they can be removed and left in the office for completion without affecting other work that may remain in the notebook. This method, shown in Fig. 35, is suggested because it affords definite advantages in keeping notes

and plotting profiles, and is particularly adaptable to the marking of cuts and fills on profile stakes. A party of three or more can be kept busy marking stakes when this method is employed.

Locating Grades on Profiles. After the field notes have been checked, profiles can be plotted in a manner similar to that shown in Fig. 33. Excellent scales for profile work are 1 inch to 5 feet vertical, and 1 inch to 50 feet horizontal. The 5 foot vertical scale gives sufficient distortion of profile lines to enable the designer to balance earth quantities with accuracy. Profiles should be inked to permit the designer to erase pencilled trial grade lines without removing the profile lines. Grade lines are placed on the profiles by eye. Accuracy comes with practice. Frequently, designers, when first laying grades, find it a good practice to compute yardages, in order to determine whether they are achieving fairly precise cut and fill balances. Every effort should be made to create a balanced earth condition within each lane. Allowances for compaction in fill sections should be made. The amount of compaction depends on the character of the soil and the methods and equipment used. For these reasons only approximate figures can be given here and the adviser should obtain better information from his own or other's experience in the area. Compaction may be estimated initially from 20 to 25 per cent. To provide for this compaction and maintain the proper balance it is obvious that the total cut in any profile must be some 20 to 25 per cent greater than the total fill in the same profile.

In laying out the grade lines on the profiles, the gradient in the direction of flow of irrigation water must be kept in mind. There must never be a contrary slope or a flat zone of any length in this direction, nor should there be sudden and large variations in the gradient. The size of the stream for a furrow or border should be adjusted to correspond to the slope, and this cannot be done if there is a great variation in the gradient of a single border or furrow. It is desirable, therefore, where possible, to locate contour or head ditches at the crest or foot of steeper slopes.

Where the slope in the direction of flow is small, the effect of swelling of soil exposed in cuts and of the settlement of fills after completion should be kept in mind. Here again the allowance that should be made for these conditions depends on the character of the soil and the subsoil and the degree of compaction resulting from machine movements over fills. Until some information is gained in a particular area, it may be assumed that fills will settle some ten per cent of their height. The swelling of cuts may be assumed at the same percentage, but never to exceed 0.2 foot. The gradient in the direction of flow can be studied in most cases by considering the grade lines on succeeding profiles, as shown in Fig. 33. In critical cases, it will be best to plot profiles in the direction of flow. If, on such a profile, the swelling and settlement indicated above would create an obstacle to successful spreading of water, excess cut and fill should be made.

In areas where border ridges and ditches normally require extra

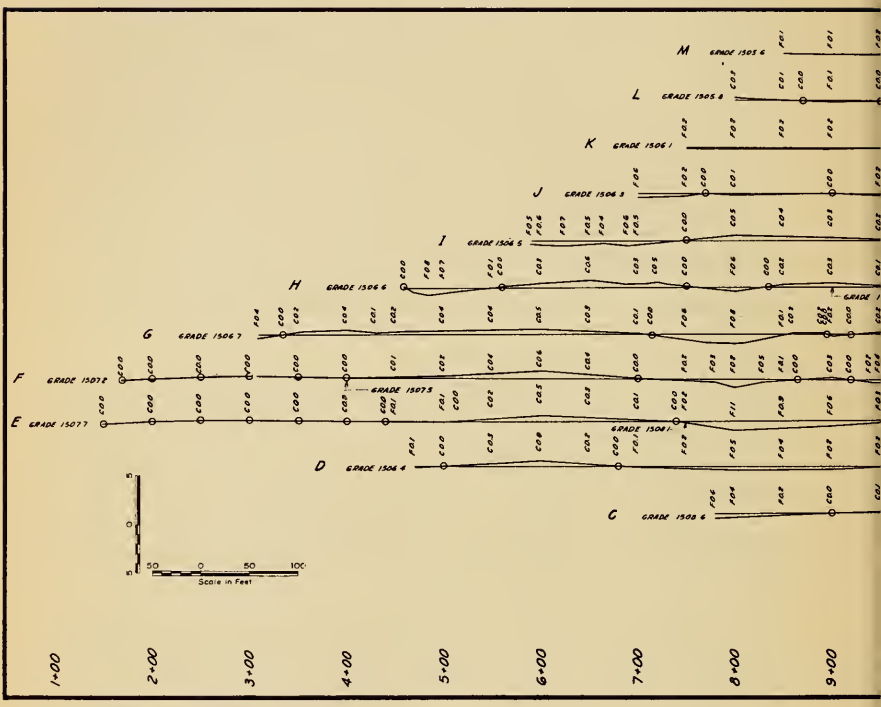


Fig. 33. Profiles and grades. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

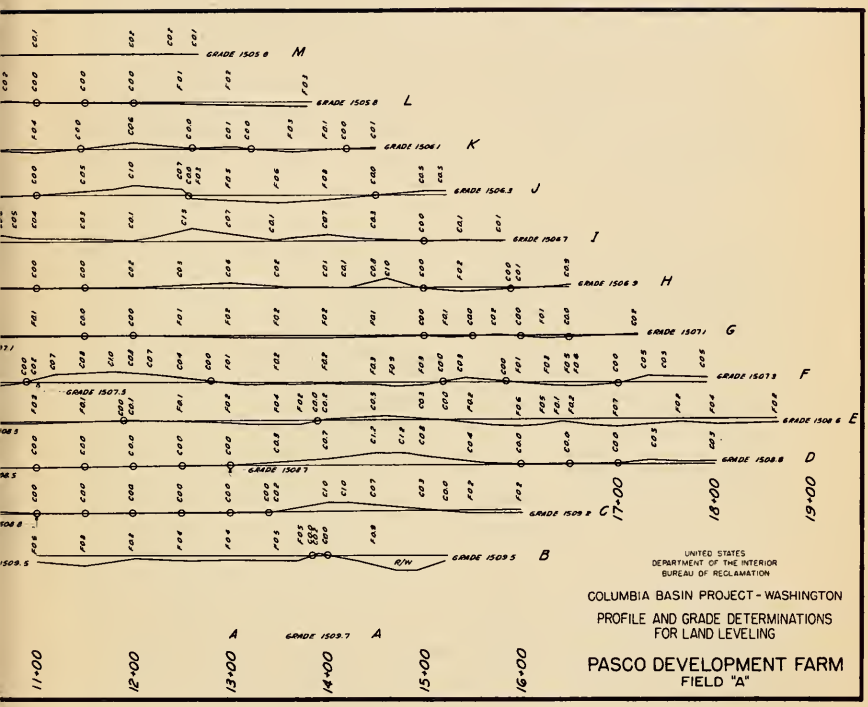


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Fig. 33 (Continued).

earth, another factor which must be considered in laying out grade lines is provision of this earth. This extra quantity could be provided by borrowing from the land adjacent to the ditch, but an undesirable situation is usually created. A depression which cannot be farmed and which will form a weed patch, is left parallel to the ditch. It is preferable to provide the extra earth required by slightly lowering the grade line in the adjacent field and moving this dirt over to form the ditch ribbon. Borders may also require additional earth, the amount depending on their size, and this too can best be provided by allowing for it in laying the grade lines for land leveling. The discussion on locating, staking, and constructing the farm ditches is in a following section, Appendix F. Under these particular conditions the layout including earthwork computations, should be done prior to laying the final grade for land leveling and adjustments made in the grade line. In this manner the necessary earth for borders, ditches, and land leveling can be provided and the maximum amount of land can be farmed.

The designer should always recognize the fact that it requires greater skill to adjust grades so that yardages can be held to a minimum than it does to move large quantities of earth. Several hours spent in adjusting grades on problem areas may save a number of equipment hours and result in a large saving in leveling costs.

Marking Stakes. Cut and fill computations are made after the grade lines are determined. These are placed on the field loose-leaf notebook sheets as illustrated in Fig. 35 for use in marking the cuts and fills on the profile stakes. A standard method of marking is used. Capital C indicates cut and capital F, fill. Letters and numbers should be made as large as the stakes will permit. They should be clearly written to permit the operator to read them from a moving tractor.

An effective method of marking stakes, which requires very little additional time, is by the use of different colored cloth. White is used for cuts and red for fills. The cloth strips are usually about 1 inch in width and 6 to 8 inches in length. The strips can be used to the best advantage by measuring their positions from the tops of the laths rather than the ground line. To designate a cut of 0.7 foot, a white strip is tied 0.7 foot below the top of the lath. A red strip in the same position would designate a fill. This method is particularly favored by tractor operators, as it enables them to pick out and visualize cuts and fills with ease. Even though stakes are marked with cloth strips, the cuts and fills should also be marked on them in figures.

The point of intersection between grade line and the profile line constitutes a point on grade. This is commonly referred to as a daylight point. Stakes located on grade are usually marked with C-0.0 indicating that no cut or fill is necessary. A cloth strip is not necessary on daylight stakes as the operator will recognize the grade stakes by the absence of the cloth. In the event that the leveling operations are being conducted by contract on a yardage basis, the

marking of stakes with cloth becomes the responsibility of the contractor.

Leveling Equipment. The equipment used by contractors or other forces doing land leveling is made up of large, efficient units. Earth, for the most part, is moved by wagon-type scrapers of 6 to 22 cubic yards capacity which, until recently, were drawn by crawler tractors. . . . . Where long overhauls are made, and in some other cases, wheel-powered units are now used. A crawler tractor is often used as a push tractor to aid in loading the wagon scrapers pulled by wheel tractors. The wheel tractors move much more rapidly than the crawlers and are, therefore, more economical for long hauls.

Land planes, bottomless scrapers, levelers, and floats play an important part in leveling operations.* All four pieces of equipment vary in size and adaptability. The 18-foot bottomless scraper is excellent for smoothing fill sections during wagon scraper operations. Properly operated, it also does a very good job of finish floating after the heavy excavation has been completed. The scraper is operated by hydraulic control and its effectiveness is entirely dependent on the operator.

The land plane is used for finish floating and does an excellent job. It derives its effectiveness from the length of the frame, which is mounted on caster wheels. An efficient size is 60 feet in length by 12 feet in width. A small-capacity bucket of the full width of the machine is located at the center of the frame in a transverse position. The vertical position of this bucket is adjusted by the operator. Cuts 0.1 and 0.2 foot in depth are made within the length of the frame. The earth in the bucket falls by gravity into any depressions encountered as the machine moves across the field. The earth is dragged, and never carried, in the bucket of the plane. Caster wheels make it possible to turn the land plane in a circle having a 30-foot radius. The bucket is used as a pivot point when short turns are made. Some land planes are made with hydraulic controls so that the bucket can be controlled by the tractor operator.

Many excellent levelers and floats have been made in farm shops and by commercial companies. Their efficiency is usually dependent on the length of the frame. The earth-moving principles are similar to those of the land plane. Levelers, planes, and floats play an important part in maintaining the smoothness of a leveled field. They are efficient in removing small irregularities left by heavy leveling equipment and by plowing and discing, and their use each year does much to improve fields for irrigation.

Construction Methods. Actual leveling operations can be commenced after the cuts and fills have been marked on the stakes. Experience has proved that leveling operations can be conducted more efficiently by commencing work next to the stake line. The operator moves the wagon scraper or other equipment into the lane and starts a cut section parallel to the line of stakes but at least 2 feet distant from it. The distance the equipment works from the stakes should be

*Author's Note—These are usually available in the West but are rare in the East.

sufficient to insure against disturbing the level of the ground around the stakes either by cutting or filling.

The operator should endeavor to cut and fill to grade along the entire distance of the stake line. This is done in order to eliminate undue turning within the lane which consumes time and hampers the operator from carrying grade. As soon as the operator believes he has brought one section the width of the machine to grade, he should move his equipment to the opposite side of the lane and repeat the procedure along the other stake line. For example, if the operation were being started in the DE lane of Fig. 33, the operator could commence work on either the lower side of the D line or the upper side of the E line. As soon as a section along one stake line is tentatively completed, the operator should move to the other line of stakes and repeat the procedure. The grade checker should check the completed section for irregularities while the operator is commencing work on the opposite side of the lane. The methods of grade checking will be discussed in the following section. The checker will mark any shortcomings in the finished sections and these should be remedied before proceeding with the center of the lane. A completed grade on each side of a lane will aid the operator materially in carrying grade from each side to the center. Some operators will prefer to complete a section 4 to 6 feet away from the first completed section. They will then cut and fill the remaining strip until the sections are connected. This aids in maintaining grade. Usually if the grade is properly laid out, the cut and fill will balance. However, factors such as variations in soil texture, moisture, and organic content will influence the amount of compaction in the fill section, and may upset this balance. If this occurs, the grade lines may have to be revised.

In large-scale operations, a bottomless scraper, land plane, or float should be used to smooth fill sections so the operators of the wagon scrapers can better judge the quality of their work. This will eliminate the need of finishing fill sections with wagon scrapers, a practice which should always be avoided as it is unduly expensive.

Grade Checking. Stake lines should be left in place until the grades have been checked and the cuts and fills have been made to the desired grade. The amount of departure from the grade permitted is usually dependent on the slope in the direction of the irrigation run. Deviation over 0.1 foot from grade should not be permitted on ground that has a slope of less than 0.2 per cent. Greater departure would be acceptable on greater slopes. It should be remembered that floating or planning will aid materially in removing minor irregularities frequently left by heavy earth-moving equipment.

One man alone can check grades by the use of a level rod and hand level. The level rod should be so made that it can be stuck into the ground and remain erect without manual support. This permits the engineer to leave the rod at a point of known cut or fill. He can then stand at an undetermined point and compare the elevation with the hand level. It is necessary for the checker to determine his *height of instrument* which, in this case, means the height of his eyes above the ground when he stands erect.

For an example of grade checking, we assume that a grade checker has an H. I. (height of instrument) of 5.5 feet. A tentative completed grade along a portion of the DE lane, as shown in Fig. 33 can be used as an example of the lane checking. The checker has placed his rod at the point where the original elevation was taken at station D-15 + 50. He then stands opposite the station in the excavated area and makes a rod reading. The cut shown at this station is 0.4 foot. If the cut has been made to grade, the checker will be standing 0.4 foot below the original ground level at the stake and he will read 5.1 on the rod. We will assume that he reads 5.1 showing that the cut has been made to grade. He then moves his rod to station D-15 and again reads the rod. The cut to be made was 0.8 foot. The checker should read 4.7 if the grade has been reached (5.5 — 0.8 = 4.7). The checker reads 4.9 in place of 4.7. This indicates that a cut of 0.6 foot has been made and 0.2 more must be made. A portion of lath, approximately 1 foot long, should then be marked C-0.2 on both sides in order to permit the operator to read it from either side and set alongside the stake at the point being checked. The next point to be read would be station D-14 + 50. The rod reading for the grade should be 4.3. We will assume that the checker reads 4.6, this point being 0.3 foot above grade. Another temporary stake is then set opposite the station on the high point indicating a cut of 0.3. We find that the remaining area opposite the stakes in the cut section is on grade. Thus all stations to and including D-10 are on grade since our grade line indicated that leveling is unnecessary. We then commence checking the fill section. At Station D-9 + 50 the stake indicates a fill of 0.2 foot. In the event the fill has been made correctly, the reading is 5.7 on the rod. The checker finds this reading and moves on to D-9 where a reading on the rod of 5.8 should be obtained if the proper fill has been made. However, the checker reads 5.6 showing that only 0.2 fill has been made. He places a short stake opposite D-9 with F-0.2 on it. He then moves to station D-8 + 50 and finds a rod reading of 5.6 whereas it should be 5.9. This requires 0.3 more fill to make grade. He then moves to D-8 where he reads 6.0 which is on grade indicating that the fill of 0.5 foot has been made. A check should be made opposite each stake along the entire profile line. Correction stakes should be placed at any point where allowable tolerances have been exceeded. These steps should be repeated along the opposite side of the lane. It is also well to check the center of the lane when the operator is of the opinion that the center has been completed. A properly adjusted hand level will be found sufficiently accurate to determine elevations at distances of under 60 feet, but should never be used for longer distances except for obtaining a general idea of relative elevations. When checking the center of the lane, it will be necessary to take into account the longitudinal slope or difference in elevation of the grade lines in the successive transverse lines.

Survey Procedure for Spot Leveling. In many instances, where farms have been previously irrigated or the land has considerable slope, a complete topographic map may not be necessary. However, the desirability of taking topography should be carefully considered

before a decision is made. In making the decision, it should be remembered that the saving of eight hours' work with one piece of heavy commercial leveling equipment would more than pay for a topographic map of an 80-acre farm.

Particularly troublesome high or low spots on previously irrigated land are usually corrected by *spot leveling*. The same practice is used on new land where only a small part of the area requires leveling. On old land, the irrigator can generally point out the problem without hesitation.

The nature axiom, "Every hill has its hollow counterpart," is true, but on flat lands the counterpart may be a considerable distance away. Knolls or depressions are more troublesome on gently sloping than on steeper ground. Earth moved from a knoll laterally, on a field possessing a gentle slope, may cause an obstruction over the entire width of the field instead of just at the previous localized knoll. Likewise, a shallow depression may be formed. A farmer, commenting on land leveling, said that at one time he had a small deep depression in his field and after several years of tedious fresno work, he now had a large shallow depression to contend with.

The grid method of staking and obtaining topographic data is recommended for *spot leveling*. This method is also an excellent one to use where the level is the only survey instrument available. The stakes are left in their original positions and are later used as construction stakes. The first step in staking the grid is the establishment of a base line. The work will be easier if it happens that the earth must be moved either in the direction of flow of irrigation water or at right angles to this direction. Sometimes the leveling may be accomplished most easily, however, by moving earth diagonally with respect to the direction of flow. In that case, the base lines of the grid should be set up in the direction of movement of earth and at right angles thereto.

Figure 34 represents a common problem on land which is generally smooth enough for irrigation but can be improved by spot leveling. The contour lines represent what the adviser sees when he examines the field. By inspection, supplemented by a few random rod readings and information from the owner if the land has been irrigated, he decides that the irrigation runs should be parallel to the fence line at the left. He will see also that the field may be smoothed up for irrigation most easily by moving earth as shown in the figure.

In this case it will be convenient to stake the first base line at right angles to the direction of movement of earth down the bottom of the depression to be filled. The first stake will be at A-2 as shown on Fig. 34. Stakes are then set at 100-foot intervals as B-2, C-2, to N-2. (Sometimes with inexperienced operators of leveling equipment, stakes should be set at 50-foot intervals.)

The transverse base lines perpendicular to the longitudinal line should then be established. If a transit is not available, the following method may be used: Any stake on the longitudinal line may be used as a pivot stake for the construction of the perpendicular. For illustrative purposes, the stake at station B-2 will be used as the pivot point.

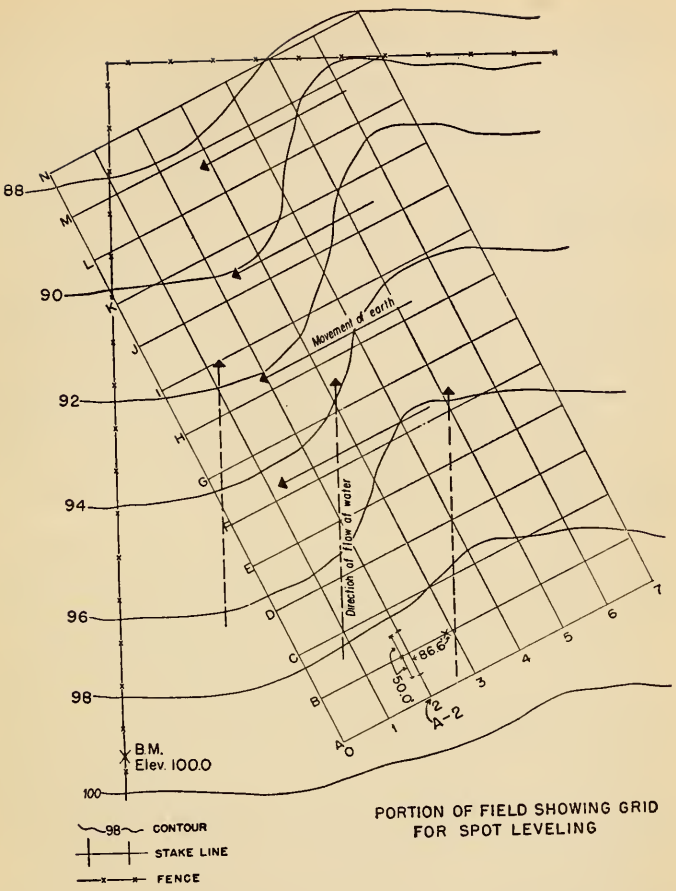

Fig. 34. Spot leveling grid. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

Stakes should be placed on the longitudinal base line 50 feet on each side of station B-2. (See Fig. 34) From one of the 50-foot stakes, an arc should be marked with the 100-foot tape. The arc should be made in the general direction of the proposed transverse line. A second arc should then be made from the other 50-foot stake. The point of intersection of the two arcs will be on a line perpendicular to the longitudinal line at station B-2. The distance between station B-2 and the

point of intersection should approximate 86.6 feet. The transverse line can then be extended by use of the tape. The stations of this line should proceed as follows: B-2, B-3, B-4, etc. Additional stakes should be placed at all major breaks in the slope occurring in the ground surface between stations. These will enable the adviser to better balance the earth quantities. They will also serve as added guides for the equipment operator. The same procedure used in establishing the B transverse or numerical line should be followed in marking another transverse line. In this case the M line would be convenient. One more longitudinal line should then be chained in. This might well be the 5 line. Stations B-5 and M-5 have been previously established in the staking of the two transverse lines. These two stakes will enable the staking party to place the remaining stakes on line. The two longitudinal and transverse lines when completed will serve as guide lines for staking the remaining area in the field by sighting in the points in both directions. The tape will be necessary only in setting plus stations at breaks occurring between stations. The transverse base lines need not necessarily be the B and M lines. Frequently, the adviser may find it desirable to locate the transverse base lines at stations such as F. and I. This is particularly true where the fields are large and the guide lines would be difficult to see if located at the far ends of the field.

Upon completion of the staking, elevations should be obtained at the base of each stake. The elevations taken should be an average of the ground surface in the immediate vicinity of the stake. Elevations above sea level are not necessary and an assumed datum may be used if desired. A method of keeping level notes and working up a topographic map on the same page of the notebook or on a 10 x 10 cross-section sheet has been used very successfully. Fig. 35 is used to illustrate this method. The scale used on the field sheet is 1 inch equals 100 feet. The space at the extreme left should be used for identifying the steps used. These will show stations, rod readings, elevation, grade elevation, and cut or fill. Other essential notes, such as bench mark, description and elevation, rod readings on bench marks and turning points, heights of instrument, etc., also are recorded.

After the rod readings have been recorded the actual elevations are computed and recorded. Contour lines are then drawn in on the field sheet. The direction of flow of water also is plotted on the sheet. Study of the data thus shown will show that the natural slope in the vicinity of station I-3 is almost at right angles to the direction of flow of water. While deep furrows might be used to irrigate this area, shallow furrows or corrugations would not work. Preparing a border system without preliminary leveling would be difficult, expensive and unsatisfactory. Moving the earth from the ridge extending diagonally from Station F-4 to K-7 into the hollow running from F-1 to K-3 along the lanes between the lettered stake lines will greatly help the situation.

The next step is to prepare the profiles shown on Fig. 36. Grade lines are then drawn on these profiles using the methods described on

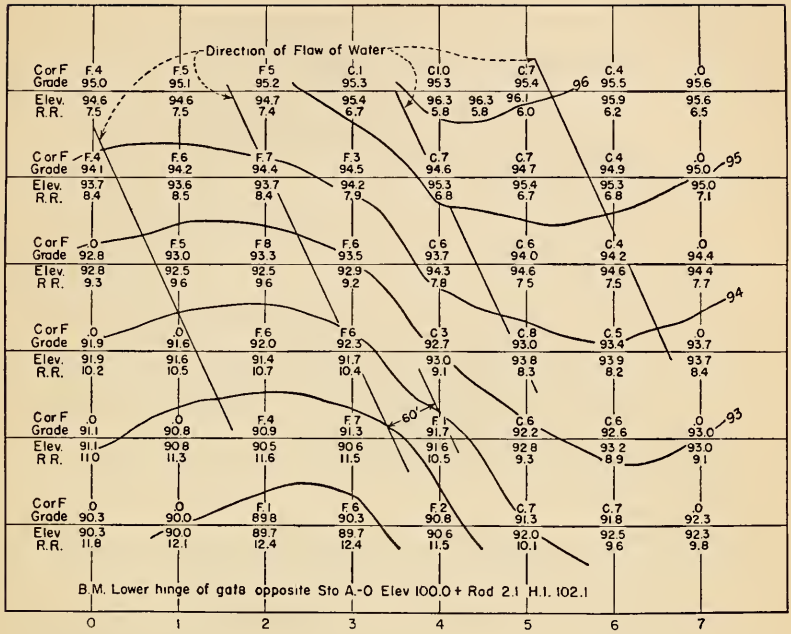

Fig. 35. Level notes and contours before leveling. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

pages 149 to 152 of this Appendix, and the cuts or fills and grades transferred to the field sheet. At first the adviser will want to plot a new sheet showing the contours as they will be when the job is done. Fig. 37 shows these. The effect of the leveling can be judged by the cross slope which would have to be taken out of a 60-foot border before and after. As shown on Figs. 35 and 37, the cross slope near Station J-4 before leveling is over a foot while after leveling it is less than 6 inches.

Marking the stakes and checking will be done on this smaller job in much the same way as on the larger over-all leveling job described earlier in this chapter.

The construction methods to be used in spot leveling will be the same as in general leveling except that, since the jobs are generally smaller, lighter equipment may be used. Also, since often this type of work is done on farms which have already been irrigated, the farmer, himself, may undertake the necessary field operations. For small jobs, the light scrapers, pulled by or attached to the ordinary farm tractor and controlled from its seat, are very useful. Just as on

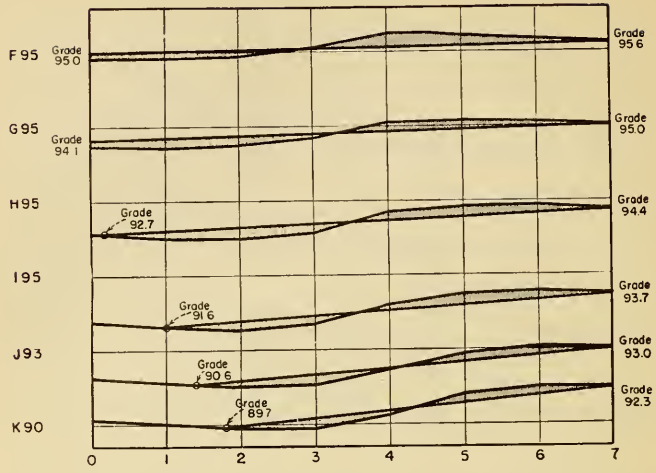

Fig. 36. Profiles and grades for spot leveling. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

the big jobs, so on the spot-leveling job, the finishing should be done by a suitable float or similar machine. Often fields that require spot leveling can be greatly improved throughout by the use of a land plane or other large finishing equipment.

As has been pointed out, the surface of a newly leveled field may rise slightly in the cuts or settle in the fills. When this occurs, it may be necessary to return to the job after the first irrigation season. If the work has been carefully done in the first place, this refinishing should not require much more than a good planing or floating.

Computation of Yardage for Leveling. Several methods are used for computing yardages for land leveling. Possibly each method has some advantage over the other when applied to specific problems. The method herein described is believed more adaptable to the yardage determination for fields being leveled where departure from uniform grades is being permitted, both longitudinally and transversely. Major breaks occurring between stations are reflected in the yardage totals. They are given consideration in the following method of computing earthwork quantities.

One or more computation sheets as shown in Figs. 38a and 38b will be required for each profile. Column 1 is used to identify the station. Columns 2 and 3 are used for recording the amount of cut or fill occurring at stations. The 4 and 5 columns show the sum of cuts and fills compiled at two consecutive station points. The distance between these points is listed in column 6. The double end areas are

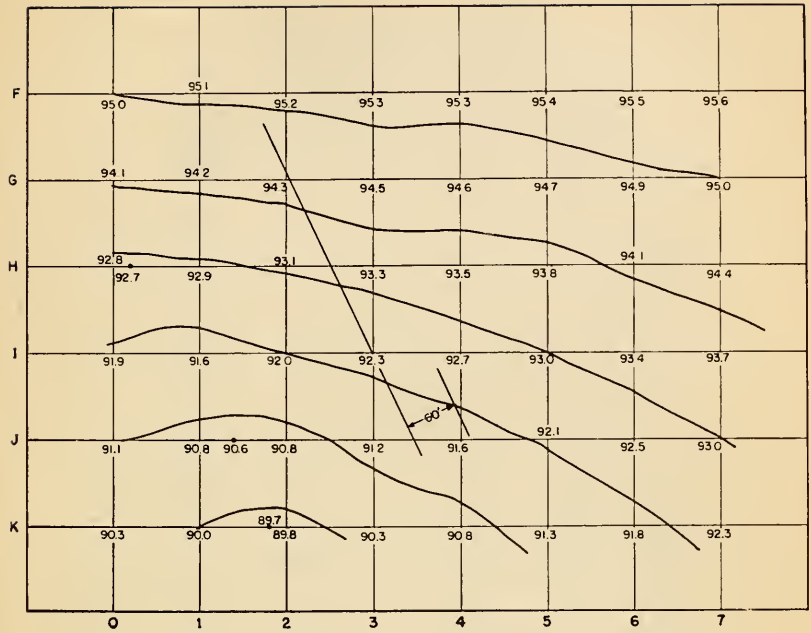

Fig. 37. Contours after spot leveling. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

placed in the respective cut and fill columns 7 or 8.

The use of the computation sheet can be best shown by an illustration. A portion of the profile on line D has been selected for the illustration Fig. 33. The first station on which a profile change occurs is at 4 + 70. A fill of 0.1 foot is made at this point. A grade point is located at the next station and the cut is listed as 0.0 in the cut column opposite station 5 + 00. The sum of the fills, which is 0.1, is placed in column 5 in the space between stations. It is customary in earthwork computations to use the average end area; however, the work can be accomplished more rapidly with calculators if the steps are confined to addition and multiplication. The totals are then divided by 2 prior to listing on the summary sheet. This explains why this column is labeled double end area in place of average end area. The distance affected by the fill which lies between station 4 + 70 and 5 + 00 is 30 feet in length and appears in column 6. The cut or fill (in this case fill) is multiplied by the 30-foot distance and gives the

LAND LEVELING EARTHWORK
COMPUTATION SHEETS
SEC. 19 T. 10 N., R. 29 E.

STATION	CUTS OR FILLS IN FEET		SUM OF CUTS OR FILLS		STATION DISTANCE IN FEET	DOUBLE END AREA SQ. FT.	
	CUT	FILL	CUT	FILL		CUT	FILL
1	2	3	4	5	6	7	8
4+70		0.1					
				0.1	30		3
5+00	0.0						
			0.3		50	15	
5+50	0.3						
			0.9		50	45	
6+00	0.6						
			0.8		50	40	
6+50	0.2						
			0.2		30	6	
6+80	0.0						
				0.1	20		2
7+00		0.1					
				0.4	50		20
7+50		0.3					
				0.8	50		40
8+00		0.5					
				0.9	50		45
8+50		0.4					
				0.7	50		35
9+00		0.3					
				0.5	50		25
9+50		0.2					
				0.2	50		10
10+00	0.0						
13+00	0.0						
			0.3		50	15	
13+50	0.3						
			1.0		50	50	
14+00	0.7						

COMPUTED BY _____ DATE _____
CHECKED BY _____ DATE _____

BLOCK NO. 1 UNIT 19
FIELD NO. A
PROFILE LINE D
SHEET 3 OF 12 SHEETS

SOIL CLASS L&2T
SOIL TYPE EPH-SA

TOTAL DOUBLE END AREA
CUTS 171
FILLS 180

Fig. 38. Computation sheet for earthwork. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

double end area in square feet which is recorded in column 8. This procedure is repeated until the profile line has been completed. Two computations sheets are necessary to complete a profile of this length. The sum of the double end areas on the first sheet of Fig. 38, which is 171 for cut and 180 for fill is then added to the results of the second

LAND LEVELING EARTHWORK
COMPUTATION SHEETS
SEC. 19 T. 10 N, R. 29 E.

STATION	CUTS OR FILLS IN FEET		SUM OF CUTS OR FILLS		STATION DISTANCE IN FEET	DOUBLE END AREA SQ. FT.	
	CUT	FILL	CUT	FILL		CUT	FILL
1	2	3	4	5	6	7	8
14+00	0.7						
			1.9		50	95	
+50	1.2						
			2.4		30	72	
+80	1.2						
			2.0		20	40	
15+00	0.8						
			1.2		50	60	
+50	0.4						
			0.4		50	20	
16+00	0.0						
17+00	0.0						
			0.3		35	11	
+35	0.3						
			0.6		65	39	
18+00	0.3						

BLOCK NO. 1 UNIT 19 SOIL CLASS 1&2 T
FIELD NO. A SOIL TYPE EPM-SL
PROFILE LINE D
SHEET 4 OF 12 SHEETS SHEET 2
COMPUTED BY _____ DATE _____
CHECKED BY _____ DATE _____
TOTAL DOUBLE END AREA
CUTS 337 + 171 = 508 = 254
2
FILLS NONE + 180 = 180 = 90
2

Fig. 38 (Continued).

sheet of Fig. 38 which is 337 for cut and no additional fill. The total cut and fill would be 508 and 180, respectively. As previously mentioned, it will be necessary to divide the total cuts and fills by two when they are placed on the summary sheet for final computations.

The summary sheet shown in Fig. 39 is used to compile and

LAND LEVELING EARTHWORK COMPUTATION SHEETS

SEC. 19 T. 10 N., R. 29 E.

BLOCK NO. 5 UNIT 19 SOIL CLASS 1 & 2 T

FIELD NO. A SOIL TYPE EPH.-S.L.

SHEET 1 OF 1 SHEETS

PROFILE LINE	END AREAS IN SQ. FT.		DOUBLE END AREAS IN SQ. FT.		LANE WIDTH	DOUBLE VOLUME IN CU. FT. (4 AND 5 x 6)		VOLUME IN CU.YD. CU.FT. x .01852	
	CUT	FILL	CUT	FILL		CUT	FILL	CUT	FILL
1	2	3	4	5	6	7	8	9	10
B	2	163							
			127	206	100	12700	20600	235.2	381.5
C	125	43							
			379	133	100	37900	13300	701.9	246.3
D	254	90							
			351	434	100	35100	43400	650.1	803.8
E	97	344							
			352	539	100	35200	53900	651.9	998.2
F	255	195							
			404	329	100	40400	32900	748.2	609.3
G	149	134							
			371	210	100	37100	21000	687.1	388.9
H	222	76							
			516	150	100	51600	15000	955.6	277.8
I	294	74							
			418	213	100	41800	21300	774.1	394.5
J	124	139							
			169	216	100	16900	21600	313.0	400.0
K	45	77							
			75	111	100	7500	11100	138.9	205.6
L	30	34							
			62	51	100	6200	5100	114.8	94.4
M	32	17							
								5971	4800
									/

COMPUTED BY _____ DATE _____ FIELD SIZE 25.96 ACRES

CHECKED BY _____ DATE _____ AVERAGE EXCAVATION 230 CU.YD/AC

Fig. 39. Summary computation sheet. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

transform the profile data into cubic yards. Column 1 is used to identify the profile line. The end areas are recorded in columns 2 and 3. It is again pointed out that the end areas are one-half of the sum of the areas compiled on the profile sheets. Referring to profile D the end areas recorded are 254 and 90. The double end area is again used in place of the average end area and for the reason previously stated.

The cuts and fills in columns 2 and 3 are added in place of being averaged. Cuts and fills resulting between profiles C and D are 379 and 133, respectively. Column 6 indicates the width of the lanes being computed. In this case it is the standard 100 feet. The double volume is the product of the lane width and the double area which is 37,900 cubic feet of cut and 13,300 cubic feet of fill. Columns 9 and 10 show the actual cubic yards. In order to expedite calculating machine operations the factor 0.01852 which is the reciprocal of 54 is used in place of 27 as all our volumes have been doubled, consequently,

$37900 \times 0.01852 = 702$ cubic yards = excavation
$13300 \times 0.01852 = 246$ cubic yards = embankment

Columns 9 and 10 are then added and the results are the actual amounts of earth moved on the field. Excavation amounts to 5,971 cubic yards and compares to the 4,800 cubic yards for compacted fill. This shows that the actual compaction was 19.6 per cent, which is close to the 20 or 25 per cent anticipated and allowed for in setting the grade lines. Thus it will not be necessary to adjust them. This is not uncommon for leveling as the top 6 inches of soil are usually porous and when moved lose volume. The field on which this work was performed is 26 acres in size. The average amount of earth moved is 230 cubic yards per acre.

APPENDIX F

SURFACE DISTRIBUTION SYSTEMS

In the surface irrigation of Chapter V the water must be carried along the high portions of the field as described for western conditions in the following quotations from the U. S. Bureau of Reclamation's *Irrigation Adviser's Guide* (Reference 28).

> In the consideration of the farm plan, a general idea of the irrigation system was developed. In the course of the topographic mapping and land leveling operations, this plan was carried further. Now it becomes necessary to work it out in detail. On most Bureau projects, the water is delivered from the Government lateral through a turnout located at the high point of the farm or of the irrigable land on the farm. From the outlet, the water must be distributed to all parts of the farm unit. Under special conditions, a second turnout may be necessary or convenient. Ordinarily, this can be secured, but usually at the cost of the landowner.
>
> In designing the irrigation system for the farm, the method of irrigation to be used must be known. The different methods in common use are described in Chapters V and VII. In those chapters will be found information on the methods suitable for various soils and topography and the size of streams and length of runs for diverse methods and conditions. The different methods are illustrated in Fig. 40. It is very unlikely that any one farm would have all of these methods. The relation of the different methods to crops and topography is indicated. Fields A and B can be rotated readily between any ordinary field crops. Topographically, field G could be used in the rotation but on most farms of this type there will be some surface waste water which can be used most satisfactorily on pasture. Since field G is in the lowest part of the farm, it makes good place for this use of waste water. Fields D and F could be used for row crops; but F, at least, is rather steep for that purpose. Fields A, B, C, and E have been leveled on an over-all basis after detailed topographic mapping. Fields D, F, and G have been spot leveled. Each basin in field C will be made level, and in field E each basin will be made level from north to south, but the slope to the east will not be changed. The soil of this field is somewhat sandy. Otherwise, this type of basin leveling which approaches the border method would not be practical.
>
> The distribution of water on the farm is generally by means of unlined open ditches excavated in earth because of the cheapness of such systems. There are, however, definite advantages in other systems. Lining of earth ditches reduces seepage losses, makes possible smaller ditches, reduces the danger of breaks or washouts, and eliminate a large part of the cleaning job. Pipe distribution systems can be buried below the ground surface. This saves a considerable area of land lost in supply and head ditches and, far more important, it does away with the weed problem in the ditches and on their banks. Open ditches, flumes, and pipes may all be used in various combinations.

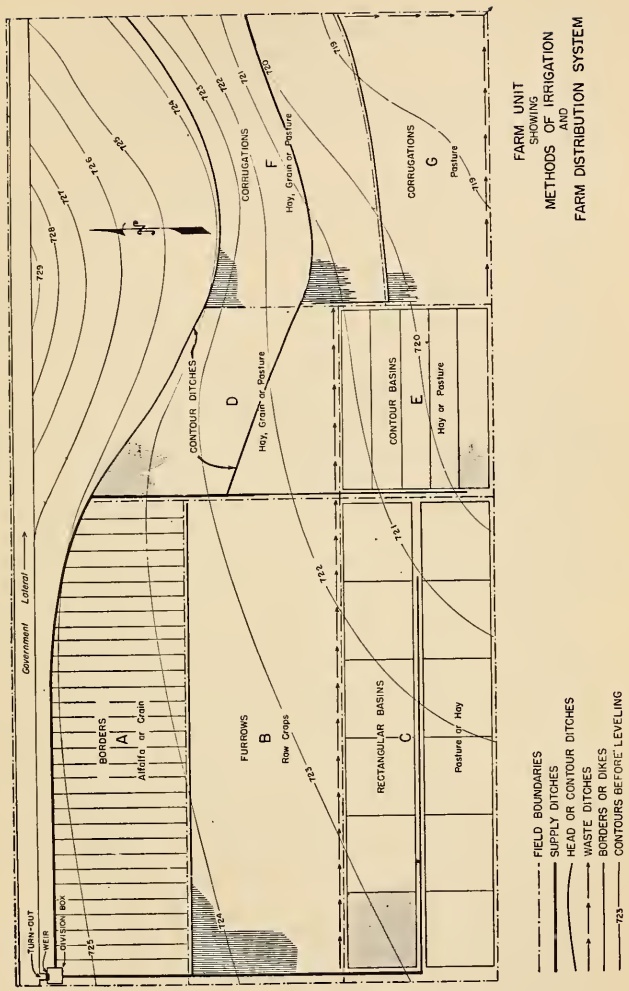

Fig. 40. Farm unit irrigated by several methods. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

Open Ditch System. In this discussion, the term *supply ditch* is used for those farm ditches which are used only, or primarily, to carry water from one point to another and only secondarily to distribute

the water on the fields. Ditches used for the latter purpose only are called head ditches or contour ditches.

The conditions shown in Fig. 40 are quite typical in that very often the supply ditch for the farm will follow along just below the project lateral, as does the one shown along the north side of field A, or along one side of the farm as that along the west side of fields A and B. In these cases, the grade of the ditch is more or less fixed by the topography.

The general location of the ditches is fixed by study of the topographic map, taking into account the lengths of runs permissible on types of soil and slopes, in accord with the data in Chapter V. Staking the ditches in the field follows. If no topographic map is available, the design and staking of the system go on at the same time. Actual construction of the ditches should not start until the entire plan has been worked out, at least in general, because it often happens that some condition encountered in later stages of the planning will necessitate changes in the earlier stages. . . .

In order to turn a large stream of water into a basin or a border through a turnout of moderate size, the water in the ditch should be several inches higher than the surface of the land being irrigated. Only small streams are required in furrow or corrugation irrigation and the furrows and corrugations are cut below the ground surface. Under these conditions, the water level in the ditch need not be as much above the ground surface. This applies to those ditches that are used for distribution directly to the land, when checked up for irrigation. . . . .

The size of stream the farmer can conveniently use will depend on the soil, topography, crop, method of irrigation, his own skill, the amount of help he has, land preparation, and irrigation system. It is seldom advisable to use less than 1 cubic foot per second, since with reasonably well prepared ditches and land, one man can handle a stream of this size even on sloping land. On the other hand, one man can handle several cubic feet per second of water on borders or basins. Care should be taken not to make the ditches too small. In spite of all possible care, they will at times become partly clogged with water weeds, grass, or sediment, and, unless they are of ample size, this will interfere with the irrigation program. The size of stream suitable for use under different conditions and methods is given in Chapters V and VII.

Earth Ditches. The minimum slope for a farm ditch should be 0.05 foot per 100 feet. Unless there is some reason for not doing so, it is customary to use a gradient of 0.1 foot per 100 feet. On very small ditches, much greater slopes can be used without danger of cutting or erosion, but on the larger ditches, steeper slopes may result in erosion of the bed or bank of the ditches. Where ditches must follow steeper slopes, it is necessary to control the gradient and thus the velocity, by means of checks or drops. The ideal velocity for a ditch would be such that the water would neither deposit nor pick up sediment. With highly collodial soils, there is a wide range of velocities within these limits, but with loose soils and under certain conditions,

there may be no such range. About all that can be done is to avoid velocities high enough to cause serious cutting of the bed or banks of the ditch. The following maximum velocities are suggested for farm ditches in different textures of soil.

TABLE X
MAXIMUM VELOCITIES FOR VARIOUS SOIL TEXTURES

Soil textures	Maximum average velocity
	Feet per second
Loamy sand	1.5
Sandy loams	2.0
Loam, silt loam, and silt	2.5
Clay loam	3.0
Gravelly soil and clay	3.5

The size of ditch which will be required for different quantities of water and gradients can be estimated from Table XI. The velocity of flow is also shown in the table. Except for steeper gradients and loamy sand or other easily eroded soils, any of the sizes and gradients shown will be safe from excessive cutting.

Ditches with a smooth concrete or other lining will carry about twice as much water on the same grades as is shown in Table XI for unlined earth ditches. The velocities will also be twice as great but they will do no harm.

Because of the great variation in the operating conditions of farm ditches, it is impossible to determine the exact size of channel required for a given stream. The sizes shown in Table XI are recommended for most conditions. Somewhat smaller ditches would serve if they could always be kept clean, smooth, and free from gravel. If the ditches are allowed to fill up with water weeds, tules, or grass, they will not be large enough. For these reasons, there would be no value in presenting more elaborate tables. Where intermediate streams or gradients are used, the proper size of ditch may be estimated with sufficient accuracy from the table. The table was made up for ditches with 1.5:1 side slopes. The water will flow an inch or so deeper in ditches with the same bottom width and 1:1 side slopes.

Fig. 41 shows cross sections of typical farm ditches. Ditches built by crowder or ditcher will be of these shapes. Ditches dug by hand or by some kinds of machinery will require less work for the same capacity if made narrower and deeper. This is especially true on hill-sides. . . . It will be noted that except for ditch number 3 shown in Fig. 41, the water level in each ditch is at or below the ground surface. In case of a ditch crossing a low spot or running on very nearly level land, it may be necessary to carry part of the water above the ground surface. In practically all cases, the water will be backed up by the use of permanent or temporary checks or portable metal or canvas dams when it is to be diverted to the land.

TABLE XI

SIZE OF FARM DITCHES REQUIRED FOR DIFFERENT STREAMS ON FOUR DIFFERENT GRADES (COMPUTED BY KUTTER'S FORMULA USING SIDE SLOPES OF 1.5 TO 1 AND n 0.030)

Grade—⅛ inch per rod; 0.05 foot per 100 feet; or 2.64 feet per mile.

Stream (cubic feet per second)	Mean velocity	Size	
		Base width	Water depth
	Ft./-sec.	Inches	Inches
0.5	0.4	12	8
1.0	.5	18	9
2.0	.6	24	11
4.0	.8	36	13
8.0	.9	48	17
12.0	1.1	60	19
16.0	1.1	72	19
Grade—3/16 inch per rod; 0.1 foot per 100 feet; or 5.28 feet per mile.			
0.5	0.5	12	6
1.0	.7	15	9
2.0	.8	18	10
4.0	1.0	24	13
8.0	1.2	36	16
12.0	1.4	36	19
16.0	1.8	48	20
Grade—⅜ inch per rod; 0.2 foot per 100 feet; or 10.56 feet per mile.			
0.5	0.8	12	5
1.0	.7	15	5
2.0	1.0	18	9
4.0	1.3	18	12
8.0	1.6	24	15
12.0	1.8	36	16
16.0	1.9	48	17
Grade—1 inch per rod; 0.5 foot per 100 feet; or 26.4 feet per mile.			
0.5	0.9	12	4
1.0	1.2	12	6
2.0	1.5	18	7
4.0	1.8	18	10
8.0	2.2	24	13
12.0	2.5	36	13
16.0			

Under some conditions, it will be necessary to carry the water across a draw or depression. Depending upon the height of the grade line above the natural ground surface, the water may be carried in an open ditch on an earth fill, in a flume, or through a pipe. The choice among these will depend upon relative costs. If the water surface is less than two or three feet above the ground surface at the lowest part of the depression, an earth fill will be most economical.

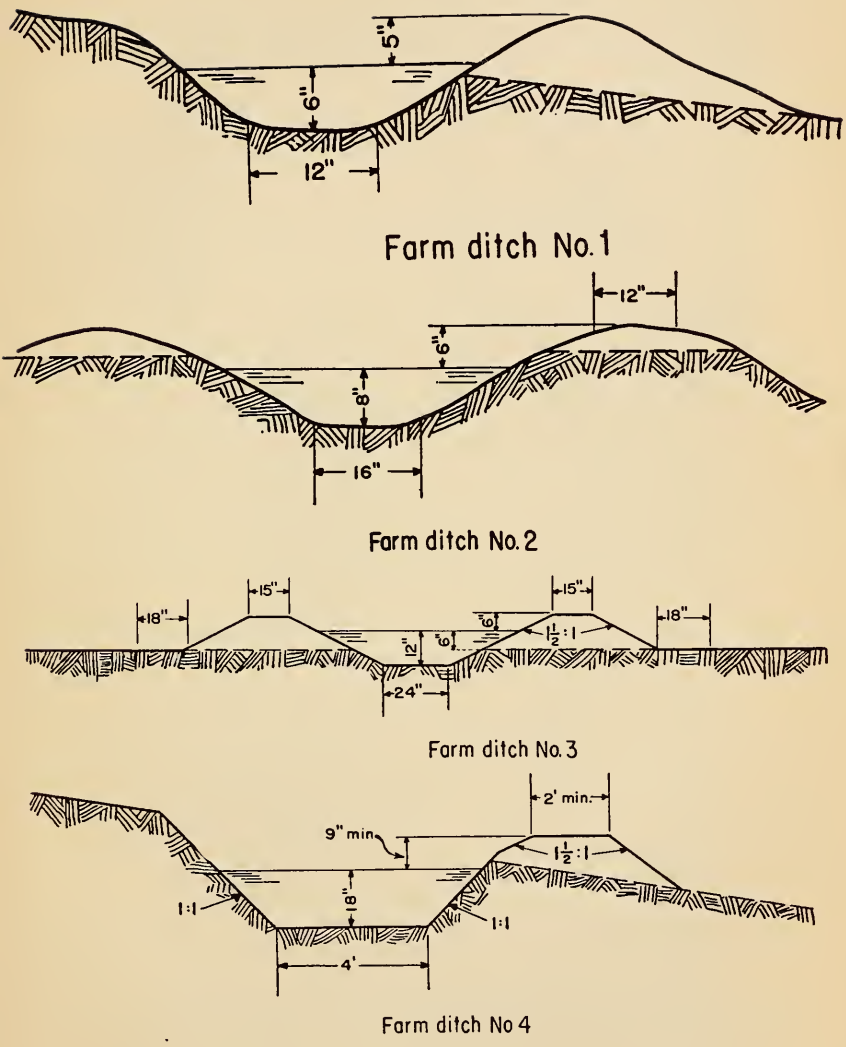

Fig. 41. Farm ditch to carry not over 1 cubic foot per second. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

For heights from 5 to about 10 feet, a flume will generally be satisfactory and where the grade line is more than 20 feet above the ground surface, it will nearly always be found best to use a pipe line. In intermediate cases, the choice will depend upon the local prices for materials and labor, and to some extent, upon the choice of the individual land owner. However, a flume is generally not considered to be as satisfactory as a siphon.

Earth fills are not always satisfactory unless they are of unusually large dimensions and even then are subject to some seepage loss and some danger of being washed out, especially if ground squirrels or other burrowing animals are numerous. If possible, fills of this type should be built of earth from high ground at the ends, rather than from borrow pits alongside. They should be built up in 6- or 8-inch layers, each well compacted. If this is not done, they will settle so much that the banks at the top will have to be built up and the bottom will be so low as to hold a pond of water when the ditch is drained.

The base should be made the full width necessary from the start. To estimate the width of base at any point, first, determine the top width from outside to outside of banks; second, find the height of the top of the banks above the ground surface at that point. Then multiply this height by a factor of 4 or more and add the top width. If the earth to be used for the embankment will pack solidly, multiply by 4; if it will not, it will be necessary to multiply by 5 or 6. For example, suppose we have a ditch 3 feet wide at the bottom and 2 feet deep to the top of the bank. The two inside slopes each will be 3 feet wide. The top of the bank should be at least 2 feet wide. We will assume that the top of the bank is 3 feet above the natural ground surface and that the soil will compact into a firm mass. We, therefore, decide to make our outer slopes two horizontal to one vertical. That means that the total width at the base will be 3 feet bottom width of ditch, plus two inside slopes of 3 feet, or 6 feet; plus two top widths of bank or 4 feet; plus two outside slopes of 6 feet each or 12 feet. This makes the total width at the base 25 feet. This fill should then be started 25 feet wide at the base. For each foot it is built up, it would be brought in 2 feet on each side. It should be built up in this way to or above the level of the expected water surface. The ditch should then be excavated in the top of the fill just as it would be in the natural ground.

Flumes. Flumes may be constructed of wood or galvanized steel flumes may be purchased. Figs. 7, 42, and 43 show designs for satisfactory wooden flumes for farm ditches. Where available, "five-quarter" or full thickness rough cedar or redwood lumber is very useful for building flumes and other wooden irrigation structures. The extra thickness of rough lumber makes for slightly longer life and it is believed that the rough surface at the junction between sides and bottom catches silt and tends to make the flume more water tight. In building small flumes, it is important that the sides be nailed to the edge of the floor boards rather than that the sides be set on top of the floor. In the latter case, there is a tendency for the bottom to sag between supports and open the crack.

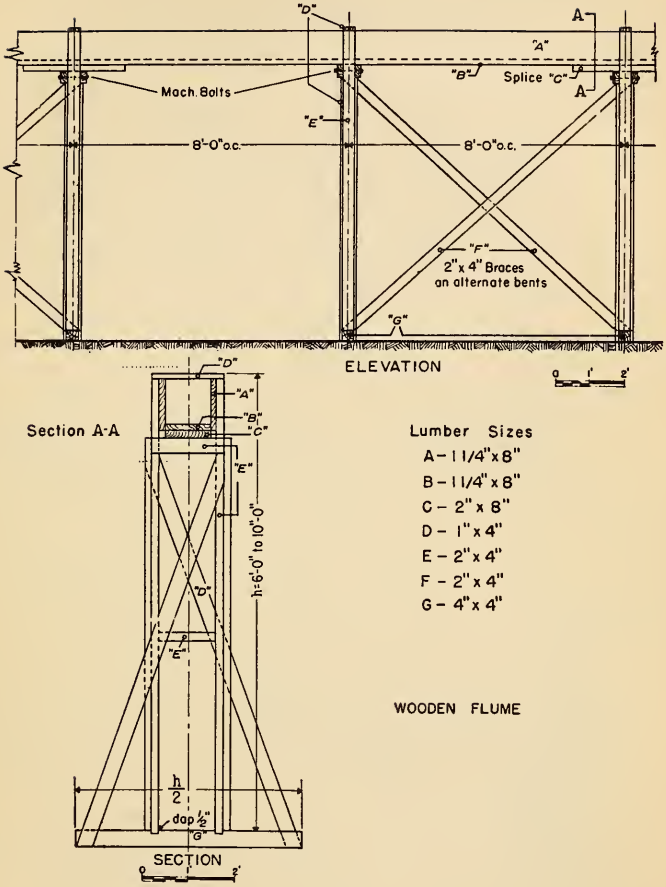

Fig. 42. Wooden flume and trestle. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

Table XII gives the size of flumes required to carry different streams on six different gradients. The table shows the depth of water flowing in the flume. In all cases, some excess depth or freeboard must be provided. Often the flume will sag slightly between supports, footings will sometimes settle somewhat, and there may be rough joints that will slow up the flow and make it deeper. Waves often

TABLE XII
SIZE OF RECTANGULAR WOODEN FLUMES REQUIRED FOR DIFFERENT STREAMS ON SIX DIFFERENT GRADES.
(Computed by Kutter's formula with n=0.014)

Stream (c.f.s.)	Size		Size		Size	
	Bottom	Depth[1] water	Bottom	Depth[1] water	Bottom	Depth[1] water
	Grade—1/8 inch per rod or 0.5 foot per 100 feet		Grade—3/16 inch per rod or 0.1 foot per 100 feet		Grade—1 inch per rod or 0.5 foot per 100 feet	
	Inches	Inches	Inches	Inches	Inches	Inches
0.5	12	7	12	5	8	4
1.0	18	8	12	9	12	5
2.0	18	12	18	10	12	8
4.0	24	16	24	12	18	9
8.0	36	17	36	13	24	11
12.0	48	18	36	18	24	15
16.0	48	21	48	16	36	12
	Grade—2 inches per rod or 1 foot per 100 feet		Grade—4 inches per rod or 2 feet per 100 feet		Grade—8 inches per rod or 4 feet per 100 feet	
0.5	6	5	6	3	6	3
1.0	8	6	8	4	6	5
2.0	12	6	12	5	8	6
4.0	18	7	12	8	12	6
8.0	18	11	18	9	18	7
12.0	24	11	18	12	18	9
16.0	24	14	24	11	18	11

develop in flumes on steeper gradients. All of these make the freeboard necessary. On flatter grades, freeboards should never be less than 3 inches on the smallest flumes and 6 inches on the larger sizes. On the steeper grades, more freeboard should be provided, especially if the flume is not straight.

It will be noted that the velocity in flumes on comparable grades is considerably higher than in earth ditches. If a flume is quite long, 50 feet or more, it will be possible to take advantage of this higher velocity. In the case of short flumes, however, the losses of head at the entrance and exist of the flume will be more than enough to make up for any saving which might be made because of the smaller friction losses in the flume.

Manufacturers and dealers in irrigation supplies sell metal flumes of different styles. They will furnish capacity tables showing the size required for streams of various sizes on several gradients. They will also furnish plans for trestles for their flumes. Metal flumes are often used in place of wooden structures because of longer life and smaller leakage.

[1]Freeboard must be allowed in addition to the water depth.

For a short flume, it is best to assume that the gradient of the water surface will be continuous through the flume. This will be exactly true if the velocity and cross sectional area of the flume are the same as those of the ditch. In the case of long flumes, where the velocity is higher on account of the lower friction losses, it will be found that the surface of the water in the flume is slightly below the ditch line gradient. If the flume is much shallower than the earth ditch, it should be set with its bottom somewhat higher than the bottom of the earth ditch. The exact method of locating the grade line for the bottom of the flume is discussed in different textbooks and sales manuals of the companies building metal flumes.

In some areas, small flumes are used in place of head ditches. This is particularly true where the water must run down a comparatively steep slope and an earth ditch would require many drop structures. Figs. 43 and 44 show wooden flumes of this type. It will be noted that openings are made in the side of the flume and that

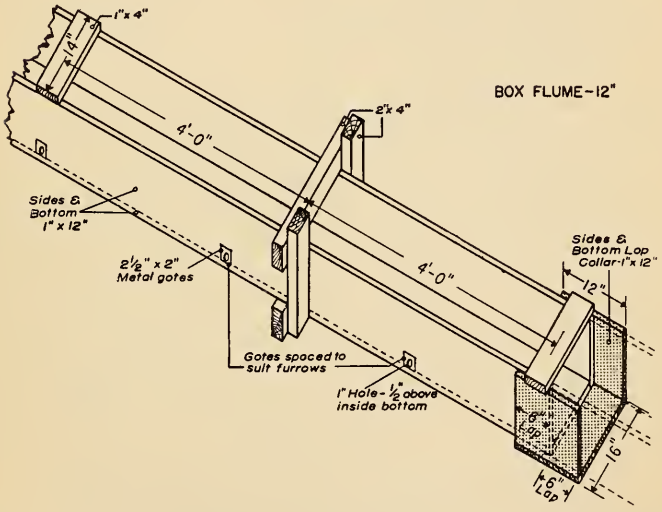

Fig. 43. Twelve-inch box flume for distributing water. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

these openings are controlled by small galvanized iron gates. This method of control of water for furrow or corrugation irrigation is very satisfactory. Flumes are often better than pipes for this purpose on steep slopes because the pressure does not build up in them.

Pipes. Pipes for use in irrigation systems may be made of wood, concrete, steel, or various other materials. Wooden pipes, unless they are made of redwood or similar decay-resistant timber or have been

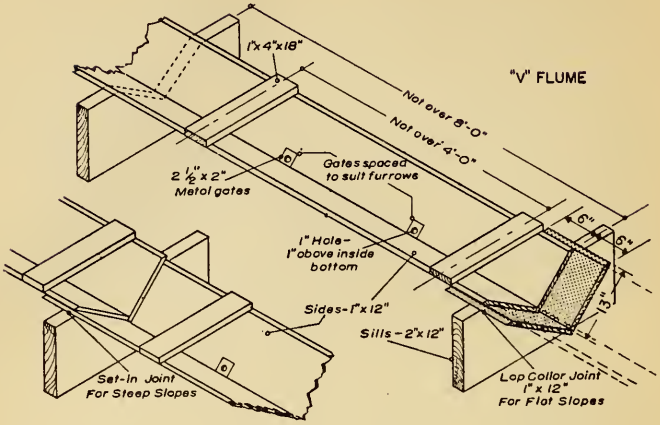

Fig. 44. V flume for distributing water. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

treated, are not very satisfactory for irrigation use. This is especially true of pipes used on the farm, which are subjected to alternate wetting and drying more than pipe lines used in project systems. Concrete pipe, if well made and properly installed, is almost permanent. Exceptions are those cases where soil or water carries an unusual amount of acid or alkali or in pump discharge lines subject to water hammer. Fig. 45 shows a suitable concrete inlet structure for 6-, 8-, or 10-inch pipe-lines. The same plan may be used for the outlet.

Table XIII gives the capacity of pipelines suitable for the farm irrigation system. When concrete pipe is used for heads up to 10 or 20 feet, it is ordinarily not necessary to reinforce it. For higher

TABLE XIII

LOSS OF HEAD DUE TO FRICTION, IN FEET PER THOUSAND FEET OF CONCRETE PIPE (computed from Scobey's formula)

($Q = 0.00169 d^{2.625} H^{0.5}$)

Stream (cubic feet per second)	Loss of head in pipe with inside diameter of					
	6 inches	8 inches	10 inches	12 inches	18 inches	24 inches
	Feet	Feet	Feet	Feet	Feet	Feet
0.5	7.2	1.6	0.49			
1.0	28.0	6.3	2.0	0.75		
2.0	110.0	25.0	7.9	3.0	0.36	
4.0		100.0	32.0	12.0	1.4	0.32
8.0			130.0	48.0	5.8	1.3
12.0				110.0	13.0	2.8
16.0					23.0	5.1

Note—A wider range of information can be obtained from Fig. 46.

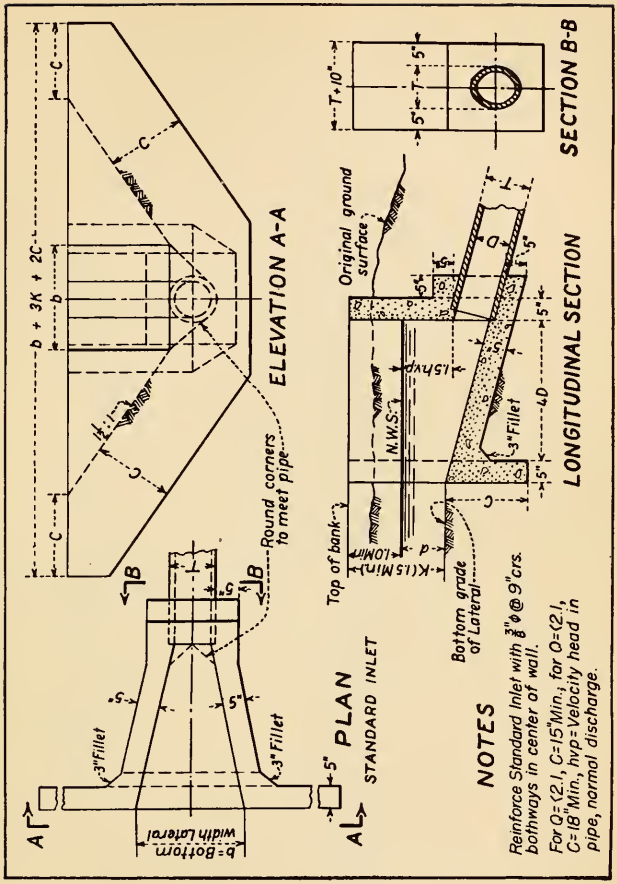
ELEVATION A-A
SECTION B-B
LONGITUDINAL SECTION
PLAN
STANDARD INLET
NOTES
Original ground surface
Top of bank
Bottom grade of Lateral
N.W.S.
3" Fillet
Round corners to meet pipe
Reinforce Standard Inlet with 3/8" ø @ 9" crs. bothways in center of wall.
For Q=12.1, C=15" Min., for Q=12.1, C=18" Min., hvp=Velocity head in pipe, normal discharge.

Fig. 45. Inlet structures for concrete pipelines. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

heads, reinforced pipe is generally used. The capacity of wooden, steel, and other types of pipe is somewhat larger than that of concrete of similar sizes because of lower friction losses. Capacity tables for such pipe will be supplied by the dealer selling the pipe.

Staking out Ditches.* To illustrate the methods of designing and staking out the ditches and structures, the system shown on Fig. 40 will be used. The first step is to determine the size required for the

*The flows of water and the ditches described in this section are larger than will be used in most supplemental irrigation—Author.

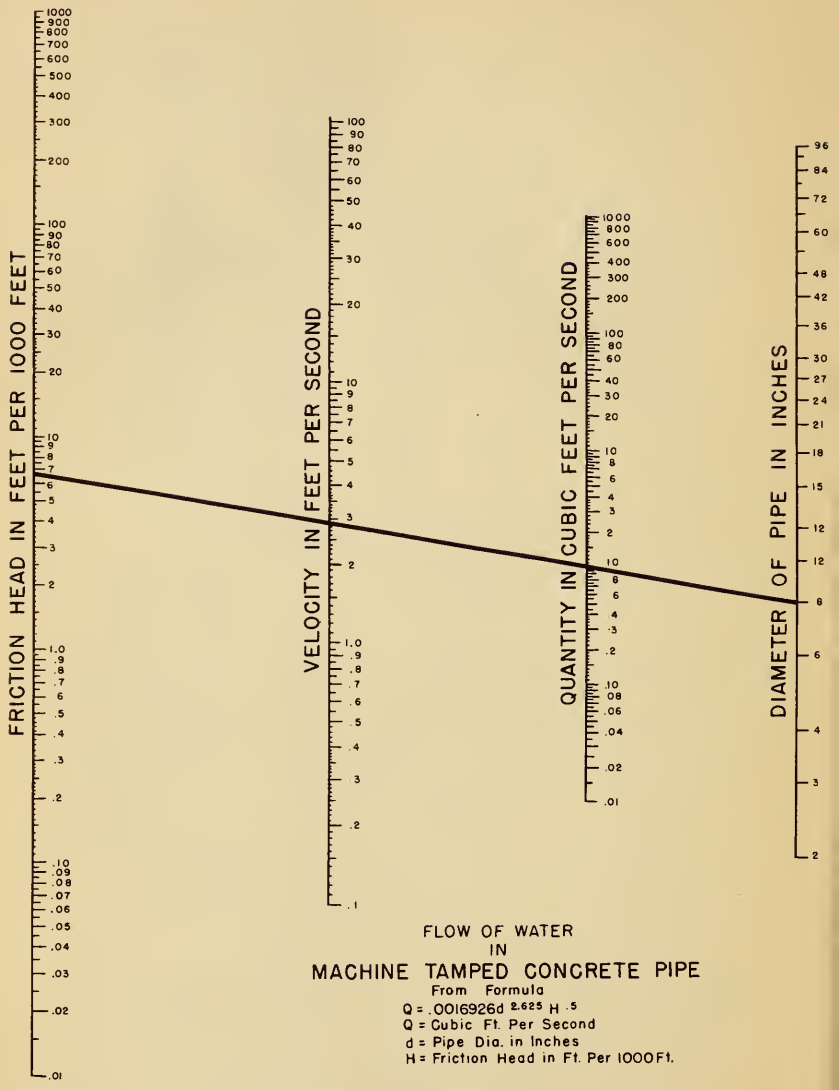
FRICTION HEAD IN FEET PER 1000 FEET
VELOCITY IN FEET PER SECOND
QUANTITY IN CUBIC FEET PER SECOND
DIAMETER OF PIPE IN INCHES
FLOW OF WATER
IN
MACHINE TAMPED CONCRETE PIPE
From Formula
Q = .0016926d 2.625 H .5
Q = Cubic Ft. Per Second
d = Pipe Dia. in Inches
H = Friction Head in Ft. Per 1000 Ft.

Fig. 46. Friction losses in concrete pipe. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

supply ditches. In Chapter V it will be found that borders or contour basins of the size shown in field E will require 4 to 8 cubic feet per second of water for satisfactory irrigation. The rectangular basins of field C are slightly larger in size and will require about the same size streams. Thus, both supply ditches should have a capacity of about 6 cubic feet per second. Under the water delivery rules of the project on which the farm is located, water will be delivered in not less than 24-hour periods. Field E could be irrigated in about 3.5 hours and field C in about 8 hours with a stream of 6 cubic feet per second. Unless much of the rest of the farm needed irrigation at the same time and was well fitted with ditches and control structures, it would be impossible to use the stream efficiently for the balance of the 24 hours. Unless the owner of this unit had other land or could arrange to let someone else have the water part of the day, the basins would have to be made smaller to be successfully irrigated with a smaller stream or some other method of irrigation used.

In order to command as much land as possible, the supply ditch along the north side of field A will be located on a gradient of 0.05 foot per 100 feet. From Table XI, we find that it will take a ditch of a size about midway between one 36 inches wide on the bottom with 13 inches of water and one 48 inches wide with 17 inches of water to carry 6 cubic feet per second on this grade. The ditch will be made 42 inches wide on the bottom to carry about 15 inches (1.25 feet) depth of water. The top width will be a little over 7 feet at the water surface. The ditch, whenever possible, will be so constructed that when it is carrying a full stream, the water surface will be just at the natural ground surface. When it is being used as a head ditch for field A, the water will be backed up by the use of a canvas or a portable metal dam or the gates in the division box at the east end of the field. . . . . .

The supply ditch will start from the outlet of the division box in any case. A stake is set at this point. The depth of water in the ditch will be 1.25 feet. The necessary cut to reach this elevation is marked on the stake. Keeping in mind that land higher than the water surface in the ditch cannot be irrigated and that it is necessary by project ruling to keep at least 7 feet from the toe of the lateral bank, the ditch running to the east is then staked. Stakes are set at 50-foot intervals, each being 0.025 foot lower than the preceding one.

At the northeast corner of field A, a division box is required where the supply ditch turns to the south down the slope. At this point, the gradient of this ditch should be increased. This will increase the velocity and thus permit a smaller size. It will also reduce the number of drops required. It is assumed that the soil on this slope is a light sandy loam and will not stand a velocity of more than 2.0 feet per second. According to Table XI, a ditch carrying 6 cubic feet per second on a grade of 0.5 foot per 100 feet would have a velocity of about 2 feet per second. The table, however, is computed on the basis of ditches in fair condition only. The velocity will be higher when the ditch is new and clean and probably would exceed the limiting velocity. It will be safer to use a grade of 0.2 foot per 100 feet which reduces

the velocity only 15 per cent. According to Table XI it will require a ditch about halfway between 18 inches wide with 12 inches of water and 24 inches wide with 15 inches of water. Therefore, the portion of the supply ditch running south will be constructed 2 feet wide on the bottom for a depth of water of 1 foot and 1.5 to 1 side slopes. This will make the ditch 5 feet wide at the water surface.

The natural gradient on the upper portion of this section is approximately 0.5 foot in 100 feet so it will be necessary to provide drops in order to hold the velocity down to a safe point. It will be convenient to make the drop and the outlet for the contour ditch supplying the lower part of fields D and F as a single structure. No other drop is required.

After this supply ditch is staked, the contour ditches in the eastern part of the farm unit will be located. About 2 cubic feet per second will be all that can be efficiently handled in each one of these ditches. Using a gradient of 0.1 foot per 100 feet, it will take a ditch about 18 inches wide on the bottom and 10 inches deep to carry this stream. The upper contour ditch is staked out around the slope on a gradient of 0.1 foot per 100 feet providing for a cut of 0.9 foot along the lower edge of the ditch.

The next contour ditch is laid out in exactly the same manner. In the supply ditch above the head of this ditch, a structure should be provided to take waste water that may have accumulated from field A in the head ditch of field B. This waste water can either be used in this contour ditch or allowed to go on down the supply ditch for use on lower land. The location of this ditch is fixed by the proper length of run between contour ditches used for flooding, as in field D, or of corrugations, as in field F. As shown in Table III, a suitable spacing is 250 to 400 feet.

The contour ditch along the north edge of field G will have a fall of about 0.2 foot per 100 feet. According to Table XI, a ditch 18 inches wide on the bottom with 9 inches of water will carry 2 cubic feet per second without exceeding the permissible velocity of 2.0 feet per second. This ditch is, therefore, staked approximately parallel to the ditch above in order to maintain approximately the same length of runs.

It will be noted that near the southeastern corner of field D, a short supply ditch must be constructed running south down the slope from the second contour ditch to supply field G. The slope in this ditch will be controlled by a check and a drop at the northwest corner of field G. It will be of the same size as the contour ditch.

The system is now completed for the eastern portion of the farm unit. Another supply ditch will be located from the turnout down the west side of the unit. This ditch, as has been noted before, will need to have a capacity of 6 cubic feet per second. The proper size and gradient will be the same as that for the portion of the supply ditch between fields A and D, that is, 2 feet wide on the bottom with a depth of 1 foot of water and a gradient of 0.2 foot per 100 feet. A division box will be required at the northwest corner of field B to divert water into the head ditch serving that field. This head ditch

should be of the same size as the contour ditches in the eastern part of the field. The ditch running east through field C should have a capacity of 6 cubic feet per second in order that the last basins may be properly irrigated. The gradient will be approximately 0.16 foot per 100 feet, and it will require a ditch about 24 inches wide on the bottom with 15 inches of water to carry the stream. The ditch should be so constructed that the water surface will be about 6 inches above the land surface, as is shown in Fig. 41 for ditch number 3.

In order to build the ditch illustrated in Fig. 41 where the two banks require more earth than is provided by the ditch excavation itself, earth must be obtained either by making the ditch itself wider and deeper or by borrowing earth from outside. Earth for borrow should be provided from adjacent basins by proper adjustment of the final gradient in the leveling plan. Sometimes the canal water carries silt and a deep section will serve to catch some of this. In other cases, a deep section may cut through into a sand or gravel subsoil, and, therefore, should be avoided. Borrow pits alongside of ditches are undesirable because they often collect waste or seepage water, harbor mosquitoes, and grow up to weeds. In the case of the ditch in field C, it will be best to borrow the necessary earth from the high side of the basins. Since these basins must be leveled, this will save some earth movement.

The most satisfactory method of building this type of ditch is to make a solid embankment of the necessary height and then to excavate the ditch in it. If ditch number 3 is made 3 feet wide on the bottom, the total width from toe to toe of the embankment will be 13 feet. This embankment should then be staked on both sides, and made about 0.5 foot high above the ground surface before cutting out the ditch. The earth excavated from the ditch section will then be sufficient to bring the banks up to the required 1 foot above the ground surface. The embankment should be brought to a uniform gradient. This means that in places it may be more or slightly less than 0.5 foot above the ground surface before excavation of the ditch. This completes the staking out of the supply and head ditches for the farm unit of Fig. 40.

On many projects, much of the land consists of a series of more or less parallel ridges and draws. If the slopes on each side of the ridges are longer from ridge to draw than can be properly irrigated in a single run, one or more contour ditches will be needed along each slope. These contour ditches generally can be most readily fed by a supply ditch running down the bottom of the draw with suitable division boxes at the head of each contour ditch. Sometimes contour ditches can be taken out of both sides of the draw at the same point. There are three advantages in placing the supply ditch in the draw rather than on the ridge. Often the bottom of the draw already has a channel that has been eroded to a stable condition and drops are not needed. The contour ditches running with the fall of the draw are longer than they would be if they ran in the other direction, and therefore, a smaller number of ditches and structures will be required.

The waste water reaching the upper ends of the draws is automatically rediverted for use in lower contour ditches.

Whether or not a supply ditch is necessary in the draw, a head ditch down the ridge is required. These ditches are run down the crest of the ridges and are used to distribute water to the slopes on both sides. A ridge ditch should be located exactly on the highest part of the ridge. If this is not done, high spots will show up on one side or the other. These high spots cannot be irrigated unless they are scraped off to a level below the water surface in the ditch. Very often, the ridges will be found to have so steep a fall that the velocity of flow in the ditch must be controlled by suitable drops. A small flume of wood or metal can be used in the place of a ridge ditch with good results.

Wherever water is applied by corrugations or furrows, and generally where borders or flooding from contour ditches are used, a certain amount of surface runoff is unavoidable. Provision must always be made to take care of this runoff. Often it is simply picked up in the next lower contour or head ditch and redistributed as indicated for field A and the upper portions of fields D and F. In other cases, special pickup ditches must be constructed. If possible, these should lead the water to a lower field on the same farm for use. In Fig. 40, such pickup ditches are shown along the lower edges of fields B, D, and G. The first two of these deliver the water into the head ditches for use on fields E or G. The waste from field G and from the lower ends of the contour ditches of field F should be delivered to a natural or artificial wasteway. On some projects, such waste water may be dumped into lower project laterals while in other cases this is not permitted. It would be possible and might be desirable to pick up the waste water at the northeast corner of field G and spread it over the southeastern section of the field.

Control Structures. An important factor in the ease and efficiency of operation of the irrigation system on any farm is the character of the water control structures. In the past too many farmers have attempted to handle their irrigation water by the use of earth dams. This not only involves a great deal of hard physical labor but invariably results in poor control. Moreover, a large part of the earth used in building dams in irrigation ditches is washed out when the dams are broken and as a result a large depression is developed in and around junctions of irrigation ditches. For these reasons, it is highly important that adequate control structures should be used from the very beginning of irrigation operations.

Such structures may be divided into three types—permanent, semipermanent, and portable. It is desirable to build permanent structures when the system is first put in, but there are three reasons which sometimes indicate the use of semipermanent or portable

structures at this time. Even with careful survey and layouts, it is sometimes found desirable to change the location or the type of structure after a few seasons' use. The second factor is the cost of construction. New settlers have to meet high costs in preparing farms for irrigation and often necessarily use cheaper forms of construction in the first instance. Permanent structures, particularly checks and drops, are very much in the way when ditches are cleaned by machine. It is sometimes found desirable to use structures which can be removed at the time of major cleaning operations. In the process of irrigation, it is often necessary to check the water in ditches temporarily, and for this purpose portable devices are used. The size of the head of water used also affects the construction. Large heads require large ditches and structures. In this case portable structures are not practical, and it generally is not economical to attempt to remove structures for cleaning operations. Every effort should be made to get the correct layout on the initial installation.

Wooden Structures. It has been found that where highly decay-resistant lumber, such as redwood or cedar, or creosoted or otherwise treated material, is available, 1-inch lumber can be used to advantage for most structures. Where available, "five-quarter" or full thickness lumber should be used. Where untreated wood of the less resistant species, such as pine and fir, is used, it is generally desirable to use 2-inch lumber. Rough lumber is generally satisfactory for irrigation structures. An exception is the lumber which is not sawed in uniform widths. This lumber is troublesome in building flumes because the sections do not fit together.

An important factor to be kept in mind in designing and building irrigation control structures is that they be ample in size. Too often the size of the structure is cut down in order to economize on labor and materials resulting in unnecessary restriction in the system.

Probably the most important structures are the division boxes which are placed at each junction of two or more farm ditches. Division boxes may be made in the form of T's or crosses. Fig. 47 shows a division box which would be suitable for the structure at the northeast corner of field A in Fig. 40. This box is designed to have a capacity of 6 cubic feet per second at the inlet and through side outlet. The outlet directly in line with the inlet has a capacity of 2 cubic feet per second. This general design can be followed in making up boxes for other uses and of other sizes. As shown, it is made with 1-inch material. Two-inch material could be used with only slight changes in the dimensions. It will be noted that grooves are provided for either structure and cutoff walls to prevent washing out.

Probably the most numerous structures on many farms are the checks and drops. The term "check" is used where under normal operation the water flows through without any change in elevation, but when the gate is shut the flow through the structure is checked,

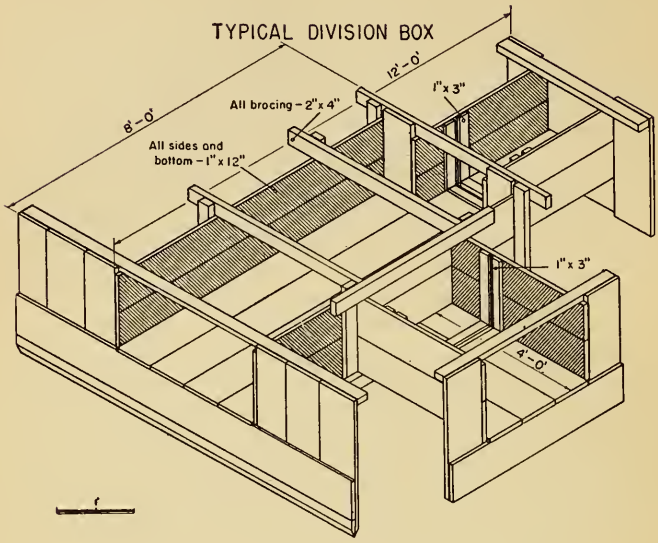

Fig. 47. Wooden division box. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

and the level of the water surface upstream is raised. Care should be exercised in designing a check to provide that the area for water passage through the check, when open, is not less than the water area in the ditch. Where the natural fall of the ground along which a ditch flows is so steep that excessive velocities would otherwise occur, drops at which the grade of the ditch is lowered one or more feet vertically are set at appropriate spacings.

In order to keep the number and height of drop structures to a minimum, the ditch grade between them should be as steep as possible. This grade, however, must not be so steep as to result in cutting of the bed or bank by the water on account of excessive velocity. Permissible velocities for different soils are shown in Table X, and the velocity for different grades and ditch sizes in Table XI. From these, it will be seen that in firm soil the smaller ditches are safe with grades up to 0.5 foot per 100 feet, and any of those used in most farm distribution systems are safe with grades of 0.2 foot per 100 feet or less. These grades can be used, therefore, between drops. If advantage is to be taken of these grades between drops, some provision must be made to prevent the *pull* of the water falling over the drop

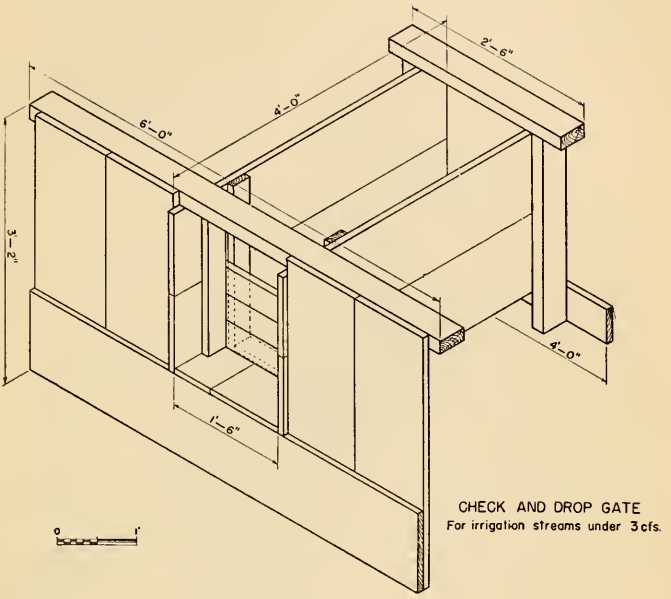

Fig. 48. Wooden check and drop. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

from speeding up the flow. The best way to do this is to make the width of the drop box less than that of the ditch. Rectangular drops such as shown in Fig. 48 should be made about two-thirds as wide as the bottom of the earth ditch. Thus, a drop 24 inches wide should be used with a ditch 36 inches wide on the bottom. Another advantage of this type of construction is that it keeps the depth of water nearly the same between drops. Fig. 48 shows a convenient type of combined check and drop for use in ditches which carry less than 3 cubic feet per second. The same type but larger size structure can be made for larger streams and for greater drops.

Under best conditions, it is convenient to use very simple border gates. These gates can be used where the soil is firm and where there is no drop from the level of the ditch to the land being irrigated. A simple plan for such a border gate is shown in Fig. 49. Where the soil is not so firm, or there is a drop from ditch to land, the type of gate shown in Fig. 50 can be used.

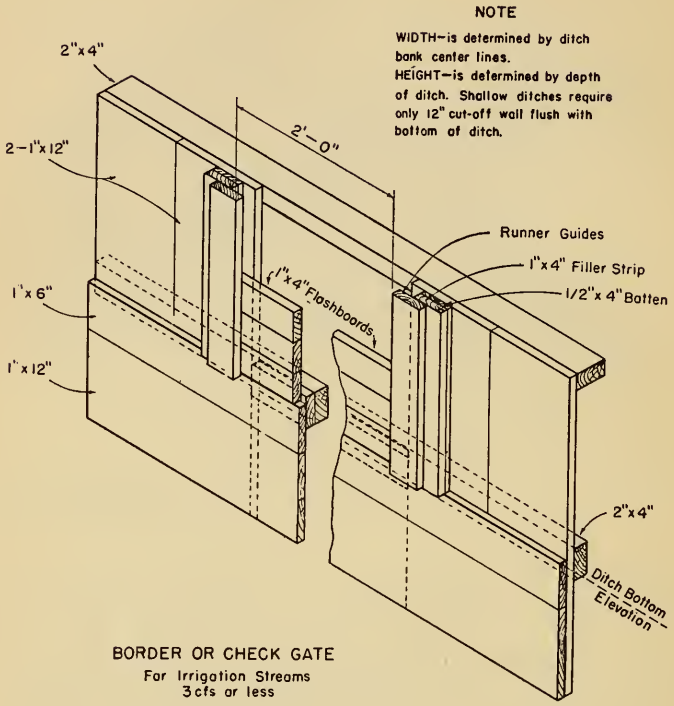

Fig. 49. Wooden border or check gate for firm soils. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

Concrete Structures and Concrete Pipe Systems

For more expensive and more permanent surface irrigation installations which reduce depreciation and labor charges, structures of concrete and various kinds of pipe are used. These are described in Reference 28 but omitted here because few new irrigators in the East will wish to install these expensive devices until they have made some alterations in their systems, know definitely what they want, and have at least begun to reap returns.

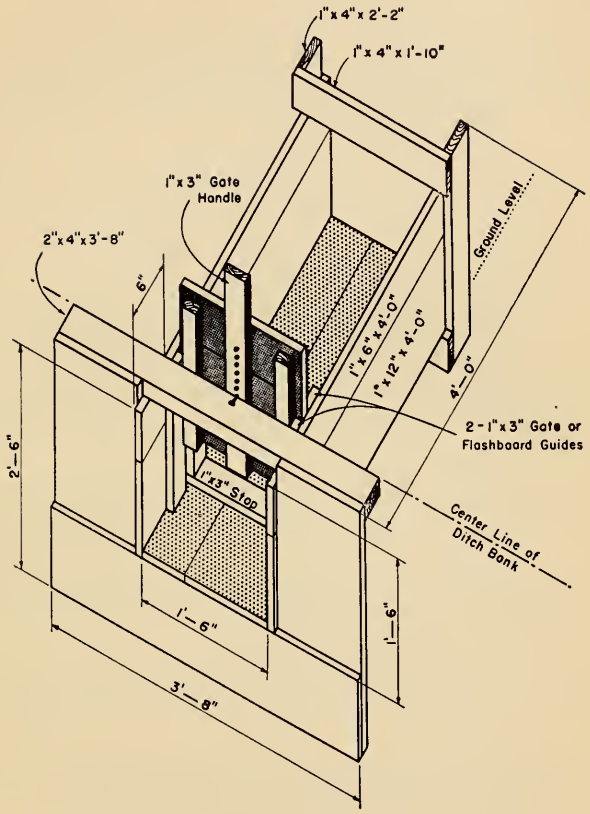

Fig. 50. Wooden delivery gate for erodible soils. (Courtesy, U. S. Bureau of Reclamation, Reference 28.)

APPENDIX G

SELECTED AND ANNOTATED REFERENCES

The arrangement is in order of dates under each subject heading. A few numbers are omitted before each subject heading to allow future insertions.

As major sources of additional and later references the reader should consult *Agricultural Index* after August 1953 and the U. S. Department of Agriculture Library *Bibliography of Agriculture* after August 1953.

GENERAL

1. **Irrigation Practice and Engineering,** Vol. I, by B. A. Etcheverry and S. T. Harding. Second Edition, McGraw-Hill Book Company, 1933.

   This is one of a three-volume set of authoritative books which completely cover the subject. Although now somewhat old and applicable largely to California conditions, the discussion of fundamentals and practical details is unexcelled.

2. **Supplemental Irrigation in Humid Regions,** by F. E. Staebner. *Agricultural Engineering,* Vol. 18, pp. 165-8 and 170, April, 1937.

   Statistical review of irrigated acreage in humid regions of the United States. Included are irrigation results, surface irrigation, orchard irrigation by means of eyelet hose, and adaption of practice to meet special conditions. Useful historically.

3. **Supplemental Irrigation on the Atlantic Coast,** by F. E. Staebner. *Agricultural Engineering,* Vol. 20, pp. 271-2 and 276, July, 1939.

   Brief survey of present status of supplementary irrigation in eastern United States, and derivation of precipitation and irrigation indexes.

4. **Supplemental Irrigation in Missouri,** by R. P. Beasley. University of Missouri, Agricultural Experiment Station, *Bulletin No. 410,* August, 1939.

   This bulletin describes in some detail most of the supplemental irrigation existing in Missouri in 1938, and provides useful comments and advice. It must be remembered that these irrigators pioneered as individuals without organized assistance and consequently could not secure good results.

5. **Determining Index of Supplemental Irrigation and Its Application,** by F. E. Staebner. *Agricultural Engineering.* Vol. 21, pp. 215-7, June, 1940.

   Outline of methods developed by the Soil Conservation

Service for determining irrigation needs in Michigan on the basis of normal rainfall and severity of drought.

6. **Thirty Years of Supplemental Irrigation Studies,** by W. L. Powers. *Agricultural Engineering,* Vol. 21, pp. 311-2, August, 1940.

   Review of practice of supplemental irrigation in that part of western Oregon where annual rainfall is from 38 inches upward while rainfall for the three summer months is under two inches. Mr. Powers gives a more detailed, but earlier, statement in the Oregon State College, Agricultural Experiment Station, *Bulletin No. 302,* June 1932.

7. **Supplemental Irrigation,** by F. E. Staebner. U. S. Department of Agriculture, *Farmers' Bulletin No. 1846,* October, 1940.

   This bulletin supersedes *Farmers' Bulletin No. 1529,* Spray Irrigation in the Eastern States, and *No. 1635,* Surface Irrigation in the Eastern States, and includes material on subirrigation and the new type of portable sprinkling irrigation.

8. **Truck and Pasture Irrigation.** Tennessee Valley Authority, Commerce Department, Agricultural Engineering Development Division, *Progress Report No. 1,* January, 1941; and *Progress Report No. 2,* January, 1942.

   In the Tennessee Valley the yearly rainfall is approximately 50 inches. However, it is often unevenly distributed, resulting in periods of drought during the growing season, a condition which greatly reduces the crop yield.

9. **Multiple Purpose Farm Ponds.** Missouri Conservation Commission, *Bulletin No. 15,* September, 1943.

   Methods of constructing and using ponds.

10. **Land Development for Irrigation.** U. S. Department of Agriculture, Farm Security Administration, Denver, Colorado, 1943.

11. **Irrigation of Arable Crops on a Rice Soil,** by R. P. Bartholowmew et al. Arkansas Agricultural Experiment Station, *Bulletin No. 455,* June, 1945, Fayetteville, Arkansas.

    This bulletin describes an early mistake in applying water, followed by very successful results.

12. **The Value of Supplemental Irrigation in Williamette Valley,** by W. L. Powers. Oregon Agricultural Experiment Station, *Bulletin No. 439,* August 1946, Corvallis, Oregon.

    A summary of results.

13. **Truck and Pasture Irrigation.** Tennessee Valley Authority.

    Published in January 1946, this supplements item 8 above.

14. **Farmers' Irrigation Guide.** U. S. Reclamation Bureau, *Conservation Bulletin No. 2*, 1939. Revised 1947.

15. **Drought, Its Causes and Effects,** by Ivan Ray Tannehill. Princeton University Press, 1947.

A rather complete book on the subject which leaves the supplemental irrigationist without any hope for relief except by his own efforts.

16. **Irrigation for More Profits,** by E. H. Davis, Irrigation Engineer. University System of Georgia, Georgia Agricultural Extension Service, *Bulletin 542*, Revised, June 1948.

A brief statement of irrigation possibilities in Georgia where the rainfall is heavy, averaging 50 inches, but where major and minor drought periods occur in the spring, late summer, and fall months.

17. **Results of Irrigation Research in Georgia—Parts I and II,** by John R. Carreker and W. J. Liddree. *Agricultural Engineering*, Vol. 29, pp. 243-44 +, 301-2 +, June and July, 1948.

A statement of results so far attained and of research necessary for supplemental irrigation in Georgia where rainfall is heavy, averaging 50 inches, but major and minor drought occurs in spring, late summer, and fall.

18. **A Handbook of Water Control.** California Corrugated Culvert Company, Berkeley and Los Angeles, California, 1949.

A portion of this recent book is devoted to developing, conveying, and applying water for irrigation, especially by the sprinkling method and by portable pipes. May also be secured from Armco Drainage and Metal Products, Middletown, Ohio.

19. **Farm Ponds in Missouri,** by Marion W. Clark. University of Missouri, Agricultural Extension Service, *Circular No. 583*, January, 1950.

Method of constructing and using ponds, including brief statement of use for irrigation.

20. **Moisture Requirements in Agriculture—Farm Irrigation,** by Harry Burgess Roe. McGraw-Hill Book Company, 1950.

A general textbook treatment of irrigation.

21. **Irrigation Principles and Practices,** by Orson W. Israelsen. Second Edition, John Wiley and Sons, 1950.

An excellent up-to-date summary of present practices, including a chapter on irrigation in humid climates.

22. **Report of the Steering Committee on Supplemental Irrigation,** by James Turnbull et al. Southeast Section, American Society of Agricultural Engineers, 1949. Mimeographed.

23. **Frenchman—Cambridge Development Farm,** by various co-

operating governmental agencies, Extension Service, University of Nebraska, College of Agriculture, Lincoln, 1950.

This reference describes the most satisfactory type of an owner-managed farm developed and operated under the best available governmental advisory services. It serves as a demonstration and experimental farm taking into account the whole balanced farm management, not simply plot studies, and describes a full-scale, over-all operation.

24. **Irrigation, the Midwest's Newest Help,** by D. Hanson. *Successful Farming,* Vol. 48, pp. 44-45, August, 1950.

A good popular article.

25. **A practical Soil Moisture Meter as a Scientific Guide to Irrigation Practices,** by G. J. Bouyoucos. *Agronomy Journal,* Vol. 42, pp. 104-7, February, 1950.

26. **Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data,** by H. F. Blaney and W. D. Griddle. U. S. Department of Agriculture, Soil Conservation Service, SCS—TP—96, August, 1950.

27. **Irrigation Engineering, Vol. I, Agricultural and Hydrological Phases,** by Ivan E. Houk. John Wiley and Sons, 1951.

A general treatise on irrigation with little attention to supplemental irrigation.

28. **Irrigation Advisers' Guide.** U. S. Bureau of Reclamation, 1951.

Excellent and authoritative information for irrigators in the West, much of which is applicable to supplemental irrigation in the East. Especially good for land leveling procedure and for surface irrigation. Quoted in Appendixes.

29. **Irrigation Reports of the Arkansas, White, and Red River Basins,** by the Inter-Agency Committee, 1951 and 1952. Mimeographed. Separate reports for Arkansas, Missouri, Oklahoma, and Texas.

These reports summarize the present and potential irrigation development in that portion of the states in the Arkansas, White, and Red River basins.

30. **Design and Evaluation of a Modified Evapotranspirometer,** by John R. Mather. Johns Hopkins University, Laboratory of Climatology, Interim Report No. 15, Seabrook, New Jersey, September, 1951.

Details of construction and operation. This is useful for the procedures by Thornthwaite and is approved by him.

31. **Supplemental Irrigation in Michigan.** Michigan State College, Agricultural Extension, *Bulletin 309,* February, 1952.

A good brief 30-page description of Michigan practice.

32. **The Water Balance in Arid and Semi-Arid Climates,** by C. W. Thornthwaite. Johns Hopkins University, Laboratory of Climatology, Seabrook, New Jersey, February, 1952.

The theory underlying Thornthwaite's theory of scheduling irrigation.

33. **Turn Water Into Dollars,** by Associate Dean Paul W. Chapman, Georgia College of Agriculture. *The Progressive Farmer,* Vol. 67, No. 5, May, 1952, page 62.

An excellent popular treatment.

33A. **Irrigation Water Rights in the Humid Areas,** by Howard T. Critchlow. American Society of Civil Engineers, *Proceedings, Separate,* Vol. 78, No. 140, July, 1952.

The article tells of the varied and indefinite status in many states.

34. **Climate in Relation to Planting and Irrigation of Vegetable Crops,** by C. W. Thornthwaite. Johns Hopkins University, Laboratory of Climatology, Seabrook, New Jersey, April, 1952. Prepared for the XVII International Geographical Congress, Section of Climatology, Washington, D. C., August, 1952.

A highly scientific and new treatment of plant growth, development, and water needs.

35. **Evapotranspiration Estimates as Criteria for Determining Time of Irrigation,** by C. H. M. von Bavel and T. V. Wilson. *Agricultural Engineering,* Vol. 33, No. 7, pp. 417-420, July, 1952.

An explanation of Thornthwaite's methods, but read also Reference 36 for further enlightenment.

36. **Determining Time and Amount of Irrigation,** by D. B. Krimgold. *Agricultural Engineering,* Vol. 33, No. 11, pp. 705-707, November, 1952.

This article endorses and elaborates on the simple and practical application of Thornthwaite's procedure for scheduling irrigation and planting as given in Reference 34. It contains a good recent bibliography as a background for Thornthwaite's theories.

37. **Climate and Scientific Irrigation in New Jersey,** by C. W. Thornthwaite. Johns Hopkins University, Laboratory of Climatology, Seabrook, New Jersey, *Publications in Climatology,* Vol. VI, No. 1, January, 1953.

Supporting theory for Thornthwaite's theory of scheduling irrigation.

38. **Biggest Yields They Ever Harvested,** by F. J. Hurst. *The*

Progressive Farmer, Vol. 68, No. 2, pp. 19 and 28, February, 1953.

A résumé of astounding irrigation results in Mississippi during the 1952 drought. Old timers said it was the driest year they ever saw.

39. **Mississippi is Not All Wet,** by Burke C. Murphy. *Irrigation Engineering and Maintenance,* Vol. 3, No. 1, pp. 10-11, April, 1953.

With an average annual rainfall of over 50 inches, supplemental irrigation increases yields as much as $200 per acre. Fertilization and close plant spacing bring results.

40. **Supplemental Irrigation in Michigan,** by E. H. Kidder and J. R. Davis. Presented at the June 1953 meeting of the American Society of Agricultural Engineers and authorized for publication as *Journal Paper 1521* of the Michigan Agricultural Experiment Station, East Lansing.

The paper describes the conditions throughout the State that brought about the present irrigation development and presents results of irrigation research.

40A. **Evaluating Irrigation Needs in Humid Areas,** by E. R. Allred and Robert Chen. *Agricultural Engineering,* Vol. 34, No. 9, pp. 611-615, 619, September, 1953.

Using IBM weather data, a scientific approach is made to determining the need for irrigation of certain crops in Minnesota. The article is useful mainly for meteorological studies.

41. **The Place of Supplemental Irrigation in Postwar Planning,** by C. W. Thornthwaite, Johns Hopkins University, Laboratory of Climatology, Seabrook, New Jersey, *Publications in Climatology,* Vol. VI, No. 2, September, 1953.

Perhaps the best explanation in some detail of the theories of Dr. Thornthwaite regarding the need for, and timing of, irrigation as affected by evaporation and transpiration. It must be read carefully if one is to understand the scheduling of irrigation and of crops for efficient production. It contains a bibliography of all publications of the Laboratory.

See also references 53, 58, 66, 102, 152, 156, 158, 210, and 211.

42. **Increased Yields with Water,** by a Committee of the Agricultural Experiment Station of the University of Missouri. To be published as a bulletin of the Station by March, 1954.

It will report studies since 1948 on claypan soil, since 1952 on alluvial soils of Southeast Missouri, and perhaps others.

SPECIAL CROPS

51. **Irrigation of Vegetable Crops.** *Gardner Chronicle* (London) Vol. 97, p. 389, January 15, 1935.

A brief summary of British practices.

52. **Influence of Irrigation on Important Small Fruits,** by W. S. Brown. Oregon Agricultural Experiment Station, *Bulletin No. 347,* pp. 1-37, June, 1936.

This bulletin gives results of a 10-year experiment with loganberries, evergreen blackberries, red raspberries, black raspberries, and strawberries as to yields, quality, costs of production and harvesting, gross income, and net profits. Conducted in the Williamette Valley, Oregon, where the average rainfall for five summer months is six inches.

53. **Farmers' Irrigation Guide.** U. S. Reclamation Bureau, *Conservation Bulletin No. 2,* 1939. Revised 1947.

54. **Irrigation Practices in Growing Alfalfa.** U. S. Department of Agriculture, *Farmers' Bulletin No. 1630,* 1940.

A discussion of the type of irrigation suitable for the growing of alfalfa. This bulletin is a revision of *Farmers' Bulletin No. 865,* Irrigation of Alfalfa.

55. **Orchard Irrigation,** by Samuel Fortier. U. S. Department of Agriculture, *Farmers' Bulletin No. 1518,* 1940.

The profits from an irrigated orchard are dependent upon a uniform distribution of water on the surface and a proper control of soil moisture from the root zone of the trees. Many failures are directly traceable to insufficiency of water supply or the manner in which it is controlled and distributed. This bulletin is a revision of *Farmers' Bulletin No. 882;* Irrigation of Orchards.

56. **Irrigation of Small Grain,** by W. W. McLaughlin. U. S. Department of Agriculture, *Farmers' Bulletin No. 1556,* 1940.

Methods of wild flooding, the border and corrugation methods in irrigating small grain, are discussed in this bulletin, as are also the preparation of the land for irrigation, the proper time to apply the water, and the quantity of water required. This bulletin is a revision of *Farmers' Bulletin No. 863,* Irrigation of grain.

57. **Irrigation (Horticulture).** Georgia Agricultural Station, *Annual Reports, No. 58,* p. 104, 1946, and *No. 59,* p. 119, 1947.

58. **Irrigated Soils,** by D. W. Thorn and H. D. Peterson. The Blackiston Company, Philadelphia, 1949.

59. **Sprinkler Irrigation Costs for Vegetable Crops in the Willamette Valley, Oregon,** by M. H. Becker and D. C.

Mumford. Oregon Agricultural Experiment Station, *Bulletin No. 463,* pp. 1-20, 1949.

A comprehensive study of costs on 137 small acreages.

60. **Irrigated Pastures,** by J. G. Hamilton. U. S. Department of Agriculture, *Farmers' Bulletin, No. 1973,* 1949.

61. **Irrigated Pastures in California,** by Burle J. Jones and J. B. Brown, revised by M. D. Miller and L. J. Booher. California Agricultural Extension Service, *Circular 125,* 1950, University of California, College of Agriculture, Berkeley.

More than 600,000 acres exist in California, using shallow rooted grasses and legumes.

62. **Value of Irrigation with Different Fertility Treatments for Vegetable Crops,** by L. M. Ware and W. A. Johnson. Alabama Polytechnic Institute, Agricultural Experiment Station, *Bulletin No. 276,* June, 1950, Auburn, Alabama.

Discusses in detail the cumulative effect of irrigation with increasing amounts of commercial and organic fertilizer. Results were satisfactory over a comprehensive 11-year experiment.

63. **Investigation of Pasture Irrigation.** Dixon Springs Experiment Station, U.S.D.A., Robbs, Illinois. Experiment 19, September, 1950.

A detail report with summary on a five-acre plot, including fertilization and pasture operation.

64. **Supplemental Irrigation for Pasture,** by R. W. Whitaker and W. F. Lytle. *Agricultural Engineering,* Vol. 32, pp. 163-5, March, 1951.

A five-acre plot in Southern Illinois shows promising results.

65. **Irrigation for Truck Crops,** by John A. Campbell. Mississippi Agricultural Experiment Station, *Circular 163,* November, 1951, State College, Mississippi.

66. **Are Little "Dry" Days the Real Corn Robbers?** by Glenn Cunningham. *Iowa Farm and Home Register,* December 2, 1951.

The theory of Colonel C. R. Pettis that short rainless periods during the crop season are costing Iowa farmers millions of bushels of corn in the average year. The article explains his newly developed theory of when and how much to irrigate, what crop losses occur nearly every year due to lack of rain, etc.

67. **Irrigation of Vegetable Crops in Southeast Missouri,** by Isaac Jack Wahba. Master's Thesis, University of Missouri, College of Agriculture, 1952.

A well-planned and well-executed, one-season experiment

on 50 acres of very flat land, using modern methods. Rainfall is heavy but imperfectly distributed.

68. **Irrigated Pastures in the Midwest.** *Farm Quarterly,* Vol. 7, pp. 58-59 and 110-111, Spring, 1952.

A good general statement of the values of irrigated pastures, especially where sprinkled.

69. **Water on Pasture Boosts Milk Output,** by A. G. Van Horn and R. H. Lush. Tennessee Agricultural Experiment Station, *Farm and Home Science Progress Report,* Vol. 2, p. 6, April, 1952.

At the Lewisburg, Tennessee Experiment Station in 1951, 24 inches of irrigation water was applied to pasture because of a bad drought. The increased value of milk produced was $121 per acre more from irrigated pasture than from a similar non-irrigated pasture. This corresponded closely with results over a four-year period, 1945-48, at the Columbia, Tennessee Experiment Station.

70. **Effective Methods of Irrigating Southeastern Pastures,** by W. J. Liddell. *Irrigation Engineering and Maintenance,* Vol. 3, No. 1, page 16 et seq., April, 1953.

This article lists several other publications on irrigated pastures, and is a good brief summary.

71. **How To Irrigate Corn,** by L. B. Nelson. *Farm Journal,* Vol. 77, No. 4, April, 1953.

Results of four years of experimenting at Scotts Bluff, Nebraska. The yields were doubled, but many details must be observed.

72. **Pointers on Irrigation.** *American Fruit Grower,* June, 1953.

An issue devoted to irrigation for the fruit grower.

73. **Irrigated Pastures.** *National Live Stock Producer,* June, 1953.

A summary of irrigated pasture practices and returns in Colorado.

In general, irrigated pastures should yield as much feed nutrients per acre as alfalfa with no more labor or irrigation. They should give greater economic return because livestock harvest the feed.

74. **Irrigating Small Acreages,** by John R. Davis. *Extension Bulletin 320,* Michigan State College, East Lansing, May, 1953.

Excellent directions for truck gardening on small acreages. A good summary.

75. **Irrigation—Your Next Big Step to More Corn,** by G. D.

Johnson. *Successful Farming,* Vol. 51, No. 7, pp. 43 and 68, July, 1953.

If acreage allotments are imposed, every bushel will be squeezed from an acre. In this article are examples of methods, yields, costs, and profits in the Corn Belt.

See also references 4, 6, 7, 8, 11, 12, 13, and 102.

PUMPING

101. **Equipping a Small Irrigation Pumping Plant,** by W. E. Code. Colorado Agricultural Experiment Station, *Bulletin No. 433,* September, 1936.

A fairly thorough discussion of the design of the pumping plant including gasoline, Diesel, and electric power; power drives; suction pumping; and discharge. Examples are given.

102. **Irrigation by Pumping from Wells,** by H. W. Gerlach. Iowa State Horticultural Society, *Transactions,* Vol. 72, pp. 360-2, 1937.

This reference and additional articles on pages 304 and 357-9 deal with pumping water and with growing cantaloupes, tomatoes, strawberries, and other crops under irrigation in Iowa. Experience with a homemade porous-hose installation and with sprinkling are described.

103. **Small Irrigation Pumping Plants,** by Carl Rohwer and M. R. Lewis. U. S. Department of Agriculture, *Farmers' Bulletin No. 1857,* December, 1940.

Throughout the United States are many farms which could be irrigated by pumping from either ponds, streams, or farm wells. This bulletin is intended to furnish owners or operators of such farms with information that will give costs and enable them to determine whether soil and water suitable for irrigation are available and what kind of irrigation plant and equipment will be most satisfactory for the purpose. This bulletin supersedes *Farmers' Bulletin No. 1404,* Pumping from Wells and Irrigation.

104. **Diesel Irrigation,** by W. H. Fullerton. *Diesel Progress,* Vol. 7, pp. 30-1, April, 1941.

Illustrated description of pumping equipment installed near Duncan, Arizona. Eight engines include four different models of Cummins Diesels. All pumps are Johnston turbines equipped with Johnston gear head.

105. **Putting Down and Developing Wells for Irrigation,** by Carl Rohwer. U. S. Department of Agriculture, *Circular No. 546,* February, 1940. Slightly revised March, 1941.

Large quantities of water are stored beneath the surface of the ground in layers of saturated sand and gravel. The most feasible method of recovering this water is by pumping from wells, and for this purpose wells capable of supplying large quantities of water at a reasonable cost are required. This bulletin furnishes comprehensive information concerning these wells.

106. **Gas Engines as Citrus Insurance,** by J. Medford. *Diesel Progress,* Vol. 8, p. 53, August, 1942.

Experience of Etiwanda Water Company, California in

providing emergency water supply for orange growers. Deep well pumping by Washington gas engines offered the solution to a serious problem.

107. **Antelope Valley Farmers Profit from Irrigation,** by M. D. Pugh. *Dieesel Power,* Vol. 21, pp. 713-4, August, 1943.

Less than one-third of the valley is under cultivation. At the present time there are about 60 Diesel powered pumping plants in the valley. Diesels are largely of the slow speed type, for the most part being single-cylinder units of 60 to 75 horse power, and are found sufficient for irrigating an average of 80 acres.

108. **Design and Operation of Small Irrigation Pumping Plants,** by Carl Rohwer. U. S. Department of Agriculture, *Circular No. 678,* October, 1943.

This bulletin is intended to furnish information necessary in keeping small irrigation pumping plants, indispensable during the present emergency, operating at high efficiency.

109. **Pumping for Irrigation, by Ivan Wood.** U. S. Department of Agriculture, Soil Conservation Service, 1950.

110. **Irrigation Pumps,** by C. N. Johnston. California Agricultural Experiment Station, *Circular 415,* August, 1952, 54 p.

The best recent treatment of irrigation pumps, their special characteristics or attributes, their application to wells, the economics of pumping, and the care and maintenance of the equipment.

See also references 1, 18, 21, 59, 201, 203, and 216.

SURFACE IRRIGATION

151. **The Corrugation Method of Irrigation.** U. S. Department of Agriculture, *Farmers' Bulletin No. 1348.* Revised October, 1931.

The corrugation method of irrigation is more adapted for application of water to steep or irregular slopes, or where the family is required to use a small stream of water, or for new land which has not yet been thoroughly prepared for irrigation. It may sometimes be used to aid in conjunction with the border method of irrigation as a means of spreading water evenly over the border strip. This bulletin describes the most approved practices to be followed when the corrugation method is employed and points out its advantages and limitations. Though old, this bulletin is still useful.

152. **The Subdivision of Irrigated Land,** by P. A. Welty. *Civil Engineering,* May 1932, pages 295-298.

Shows that irrigation layouts that fit topography are only two-thirds as costly as rectangular layouts. It is fair to assume that leveling and irrigation will be similarly cheaper.

153. **Porous Hose Irrigation,** by O. E. Robey. Michigan State College, Extension Division, *Bulletin No. 133,* July, 1933.

This is a discussion of the need for irrigation in Michigan, the use of porous hose for distributing the water, the improved quality and quantity of crops, the selection of pumps and equipment, and the cost of irrigating. It appears to have been applied on areas of ten acres or less.

154. **Development of Porous Hose Method of Irrigation in Michigan,** by O. E. Robey. *Agricultural Engineering,* Vol. 15, pp. 382-3, August, 1934.

Distribution of irrigation water by means of porous canvas pipe 2½ inches in diameter laid along the center row of truck gardens.

155. **The Border Method of Irrigation,** by Samuel Fortier. U. S. Department of Agriculture, *Farmers' Bulletin No. 1243.* Revised October, 1937.

The border method of irrigation described in this bulletin, while but one of the several methods followed in western states, is well adapted to a variety of soils and crops and is growing rapidly in public favor.

156. **First Aid for Irrigator.** U. S. Department of Agriculture, Farm Security Administration, Office of Area Engineer of Water Conservation and Utilization, Denver, Colorado, May, 1943.

This is an excellent set of whiteprint plans drawn in perspective projection giving detailed instructions for distribut-

ing irrigating water. Many of these plans are used as illustrations in the foregoing pages.

157. **A Practical Method of Determining Proper Lengths of Runs, Size of Furrow Streams, and Spacing of Furrows on Irrigated Lands,** by Wayne D. Criddle. U. S. Department of Agriculture, Soil Conservation Service, 1949.

158. **Land Preparation for Irrigation and Drainage,** by Ivan Wood. Presented at the winter meeting of the American Society of Agricultural Engineers, Chicago, December 1950.

Irrigation and drainage are combined at little additional cost in Iowa and elsewhere.

159. **The Border Method of Irrigation,** by J. C. Marr. California Agricultural Experiment Station, *Circular 408,* March, 1952, 23 p.

A detailed explanation of this popular and efficient method.

See also references, 1, 7, 14, 23, 28, 31, 53 to 56 inclusive and 102.

160. **Contour Furrow Irrigation,** by Karl O. Kohler, Jr. U. S. Department of Agriculture, Soil Conservation Service, *Leaflet 342,* September, 1953, 8 p.

Explains the advantages, disadvantages, and precautions to be observed. The method is useful for certain soils, topography, and row crops.

SPRINKLING

201. **Drought Protection by Spray Irrigation,** by K. Laux. *Engineering Progress,* Vol. 17, pp. 378-9, December, 1936.

Description of portable Perrot-Deutz Diesel pump for spray irrigation from open bodies of water; data on overhead irrigation practice.

202. **Irrigation by Sprinkling,** by J. E. Christiansen. *Agricultural Engineering,* Vol. 18, pp. 533-8, December, 1937.

Report on the University of California experimental study of irrigation sprinkling with portable systems. This study gives uniformity of distribution, evaporation losses, hydraulic characteristics, costs, and ground conditions for success in a sprinkler system.

203. **Sprinkler Irrigation in Humid Sections of Oregon,** by F. E. Price. *Agricultural Engineering,* Vol. 19, pp. 161-2, April, 1938.

Review of expansion of overhead irrigation of vegetable crops in Western Oregon during recent years. Examples of use and cost.

204. **Low Pressure Sprinkler Irrigation,** by F. W. Duffer. *Agricultural Engineering,* Vol. 20, pp. 97-8, March, 1939.

Engineering and cost data on the construction and operation of portable rotary sprinkler systems of irrigation.

205. **Hydraulics of Sprinkling Systems for Irrigation,** by J. E. Christiansen. *Agricultural Engineering,* Vol. 22, p. 89, March, 1941.

Uniformity of application of water by sprinkling systems. Spacing, arrangement, and operation of irrigation sprinklers so that there can be absorption without run-off.

206. **Hydraulics of Sprinkling Systems for Irrigation,** by J. E. Christiansen. American Society of Civil Engineers, *Transactions,* 1942, pp. 221-39, 240-50, 586.

Describes low-cost portable systems with respect to (1) the hydraulic characteristics of rotating sprinklers, (2) loss of water by evaporation, and (3) the hydraulic characteristics of sprinkler lines.

207. **Irrigation by Sprinkling,** by J. E. Christiansen. University of California, *Bulletin 670,* 1942.

208. **Design of Sprinkler Irrigation Systems,** by Albert Molenaar. State College of Washington, 1948.

209. **Design Procedure for Portable Sprinkler Irrigation,** by A. W. McCullough. *Agricultural Engineering,* Vol. 30, pp. 23-28, January, 1949.

210. **Sprinkler Irrigation.** U. S. Bureau of Reclamation. Revised December, 1949.

A general and fundamental treatment.

211. **Sprinkler Irrigation,** *Fortune Magazine,* June, 1950.

An up-to-date popular treatment.

212. **Pipeline to Profit—Portable Sprinkler Irrigation,** by the Aluminum Company of America, 1951.

A conservative and brief summary. Shows several typical layouts for portable pipe sprinkler systems.

213. **Sprinkler Irrigation,** by Oregon State College, Corvallis; State College of Washington, Pullman; and University of Idaho, Moscow; 1952.

An excellent brief, popular treatment.

214. **Sprinkler Irrigation Handbook,** by Rain Bird Sprinkler Manufacturing Company, Glendora, California, 1952.

An excellent, late, and rather complete treatment of sprinkler system information and usage. Perhaps the best handbook by a commercial company.

214A. **Effects of Irrigation Droplet Size on Infiltration and Aggregate Breakdown,** by G. Levine. *Agricultural Engineering,* Vol. 33, No. 9, pp. 559-560, September, 1952.

Size of drops from sprinkler systems were varied, showing that the size is of importance when designing a sprinkler system.

215. **From the Old to the New,** by Gordon P. Hawkins. *Irrigation and Maintenance,* Vol. 3, No. 1, page 6 et seq., April, 1953.

Sprinkling has replaced surface irrigation in parts of the Spokane Valley, Washington. In some cases groups of farmers are being served by one set of pumps and pressure mains.

216. **Irrigation in the East,** by Frank Miner, delivered at the Washington, D. C. Section, American Society of Agriculture Engineers, December, 1952.

A good general summary with a detailed example.

217. **Standards for Design, Installation, and Performance of Sprinkler Irrigation Equipment,** by the Sprinkler Irrigation Association and the Sub-committee on Sprinkler Irrigation of the Committee on Irrigation, Soil and Water Division, American Society of Agricultural Engineers. *Irrigation Engineering and Maintenance,* Vol. 3, No. 2, page 16 et seq., May, 1953.

These standards, including the responsibilities of both the buyer and seller, have been approved by both of the foregoing organizations in November, 1952 and February, 1953. Some irrigation advisers and experts recommend only suppliers of

irrigation equipment who agree to operate in accordance with the foregoing "Standards etc." See pages 84 to 87 of this book.

218. **Secondhand Rain.** *Farm Management,* Vol. 2, No. 7, pp. 46-63, June, 1953.

The advantages and disadvantages of sprinkler irrigation how sprinklers work, selecting the system, costs, conservation values, and suggestions for pump purchasers.

An excellent, full, up-to-date treatment.

219. **Sprinkler Irrigation Costs and Practices,** by M. H. Becker. Oregon Agricultural Experiment Station, *Bulletin 532,* 1953, 24 p.

Covers the year 1950 in the Willamette Valley, Oregon.

220. **For Hale and Hearty Acres,** by Crysler Industrial Engines. *Engineering News-Record,* p. 79, Nov. 12, 1953.

An advertisement describing 70 acres of corn and 50 acres of soybeans irrigated by sprinkling during the very dry summer of 1953 near Williamsburg, Virginia. Water from the James River was pumped at the rate of 960 gallons per minute, 14 hours per day, 7 days per week. Not only did this farmer save his crops during an especially dry season but the yields were increased 100 per cent over normal yields.

221. **Commercial Irrigation Companies.**

Such companies will furnish literature, designs, estimates, and bids on sprinkling systems.

See also references 7, 12, 13, 18, 28, 59, 63, 64, 67, 68, 102, and 110.

FILMS

These apply largely to western irrigation but they are also adaptable to eastern supplemental irrigation.

251. **Irrigated Pastures.** Prepared by U. S. Bureau of Reclamation, 1943. (Sound, color, free-loan, 25 minutes.)

Illustrates methods of irrigating pastures.

252. **Irrigation Farming.** Prepared by the U. S. Department of Agriculture, 1945. (2 reels, 16 mm. and 35 mm., sound, b/w. 17 minutes.)

Presents some irrigation problems and their solution in southwestern states. Emphasizes the need of a well-planned layout and water control system in irrigation farming. Shows some standard methods of planning and installing or revising farm irrigation systems.

253. **Irrigation in Nebraska.** Nebraska U-AV, 1949. (Sound, color, 42 minutes.)

Fundamental irrigation practices and procedures.

254. **Right as Rain.** Modern TP, 1951. (Sound, color, free-loan, 22 minutes.)

Sponsored by the Aluminum Company of America. Gives details of portable sprinkler irrigation and an actual test of sprinkler-system supplemental irrigation in Illinois.

255. **Right as Rain and New Worlds to Conquer.** Farm Flm Fd, 1953. (Sound, color, free-loan, 35 minutes.)

Sponsored by the Aluminum Company of America. The first film presents the results that can be obtained by sprinkler irrigation through large aluminum pipe. The second film is a "challenge to youth."

For other and more recent films see a late edition of Educational Film Guide, published by the H. W. Wilson Company, 950 University Avenue, New York 52, New York. Arrangements to choose and secure the films can usually be made through your local film distribution agency, often connected with your university or school system.

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Date Due

Due	Returned	Due	Returned
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